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EP A 0019706
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(54) **Self-sustaining solenoid**

(57) A self-sustaining solenoid which is adapted so that when applying an operating current to a coil 40, an armature 16 disposed in the coil is attracted into contact with a core 13. A magnetic yoke 11, 12 is provided to extend between the core 13 and the end portion of the armature projecting out of the coil, and a permanent magnet 14 is disposed at one end on the magnetic yoke. When the armature 16 is held in contact with the core, magnetic fluxes emanating from the permanent magnet mostly pass through the armature, the core and the magnetic yoke, and even if the operating current is cut off, the armature is retained in contact with the core. A magnetic gap 44 is provided through which the magnetic flux of the permanet magnet 14 mostly passes when the armature is out of contact with the core, the magnetic flux resulting from the application of the operating current passing across the magnetic gap 44.

FIG. 4

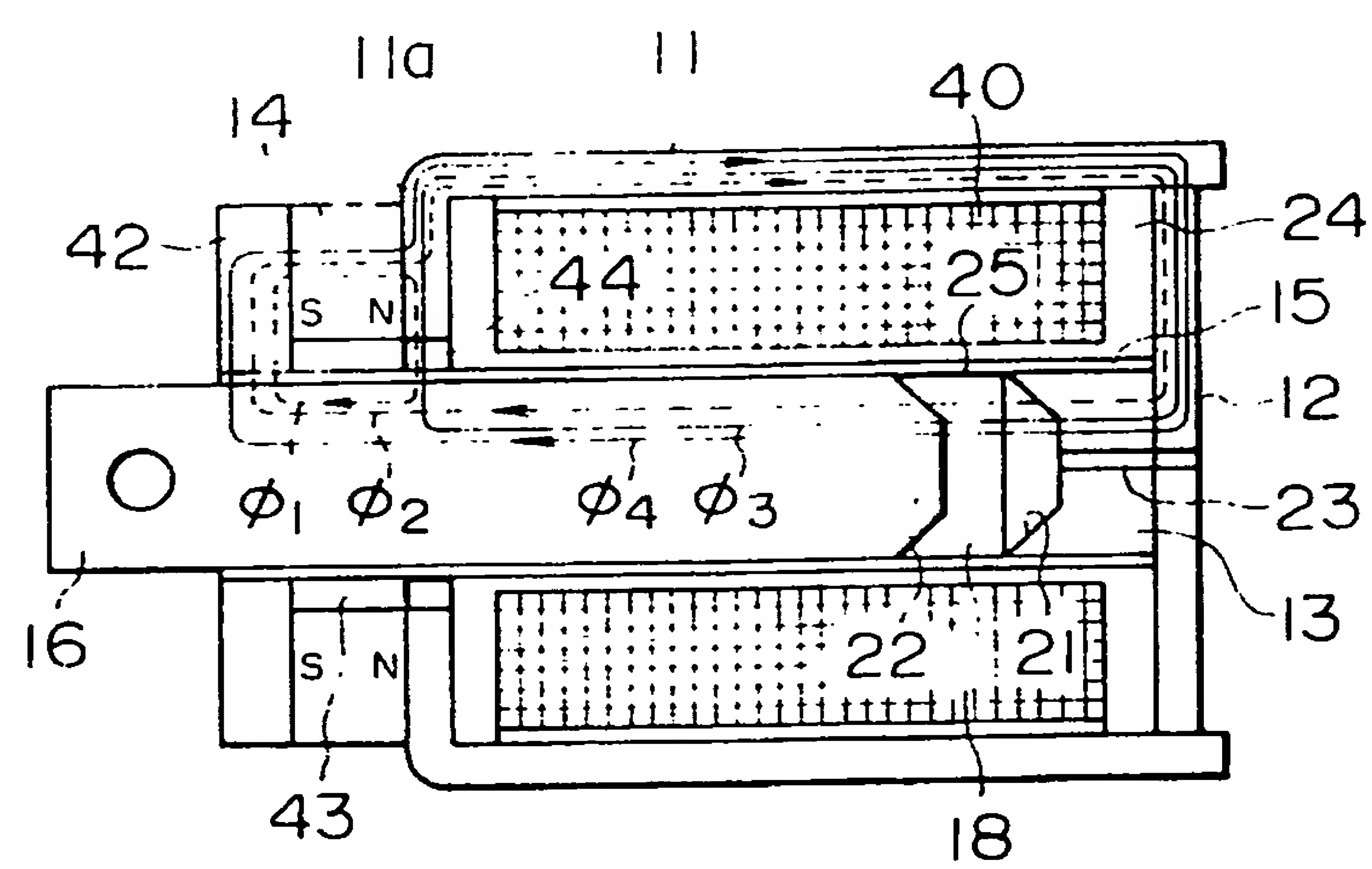

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FIG. 1 PRIOR ART

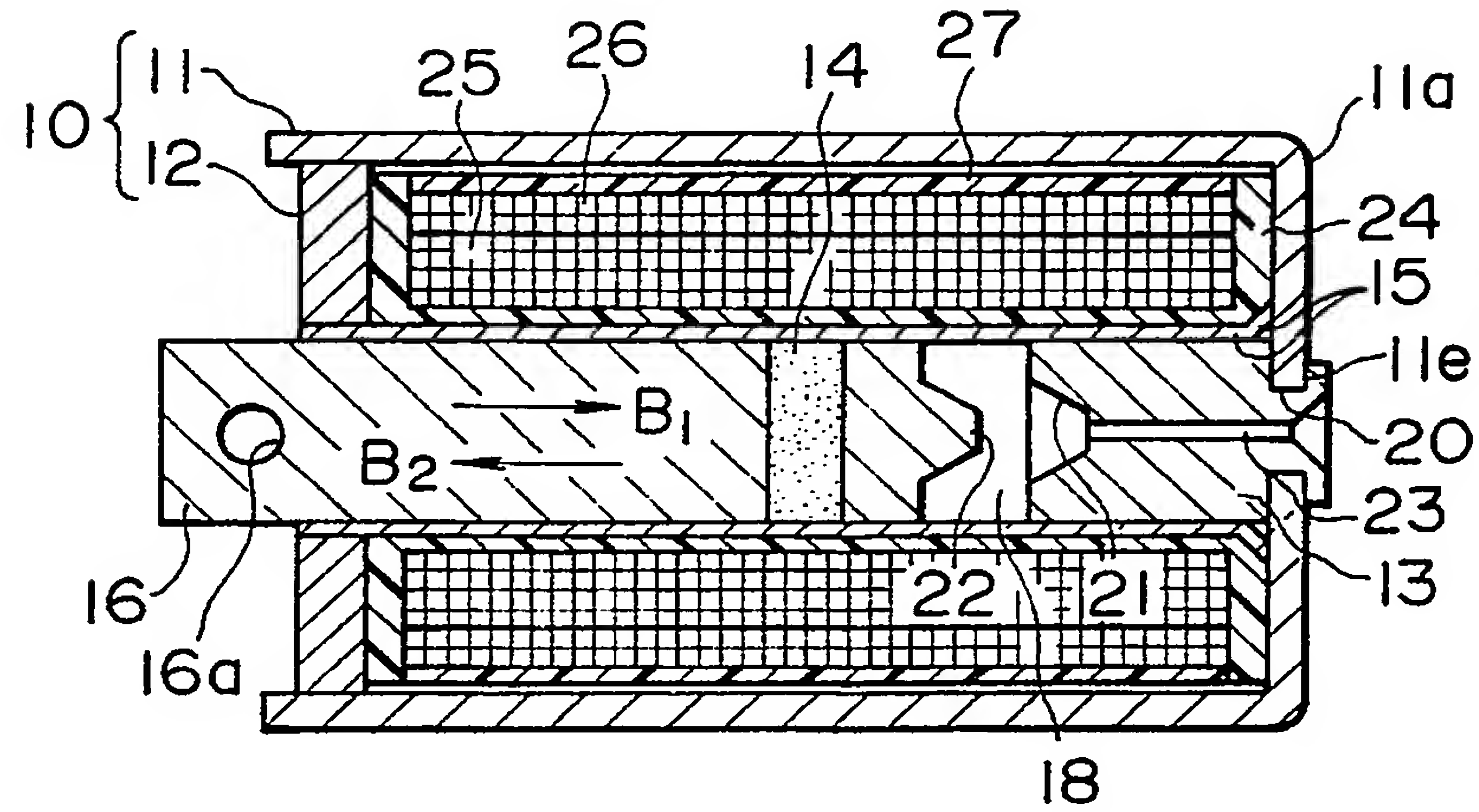

FIG. 2A PRIOR ART

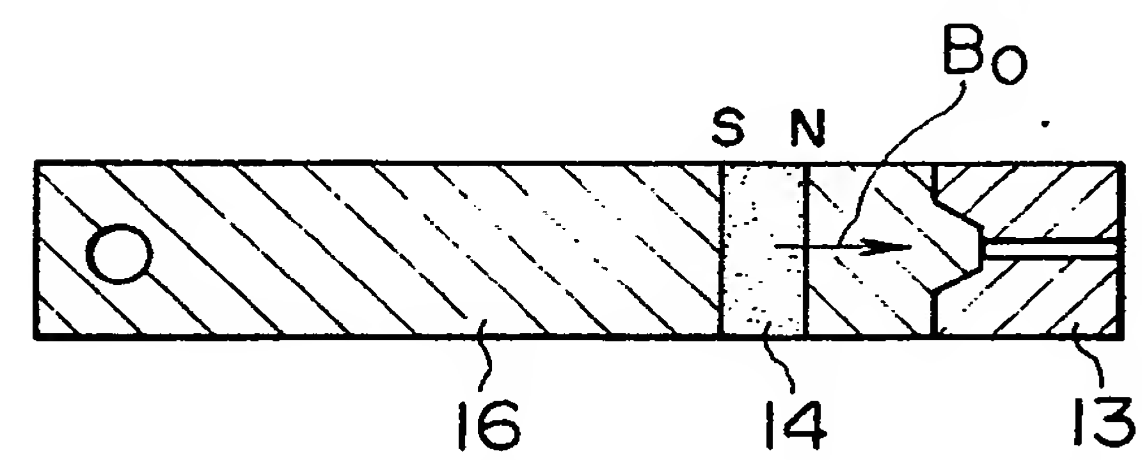

FIG. 2B PRIOR ART

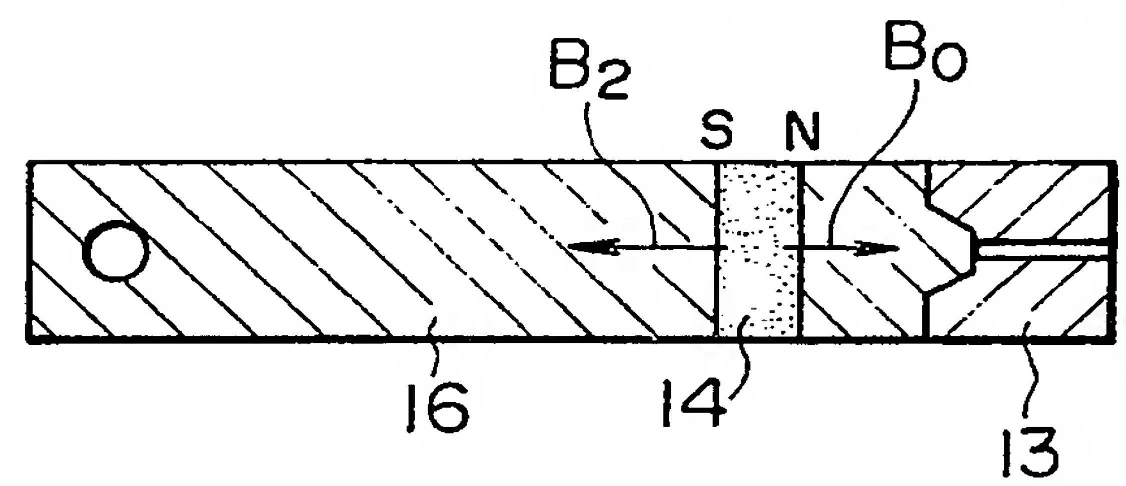

FIG. 3

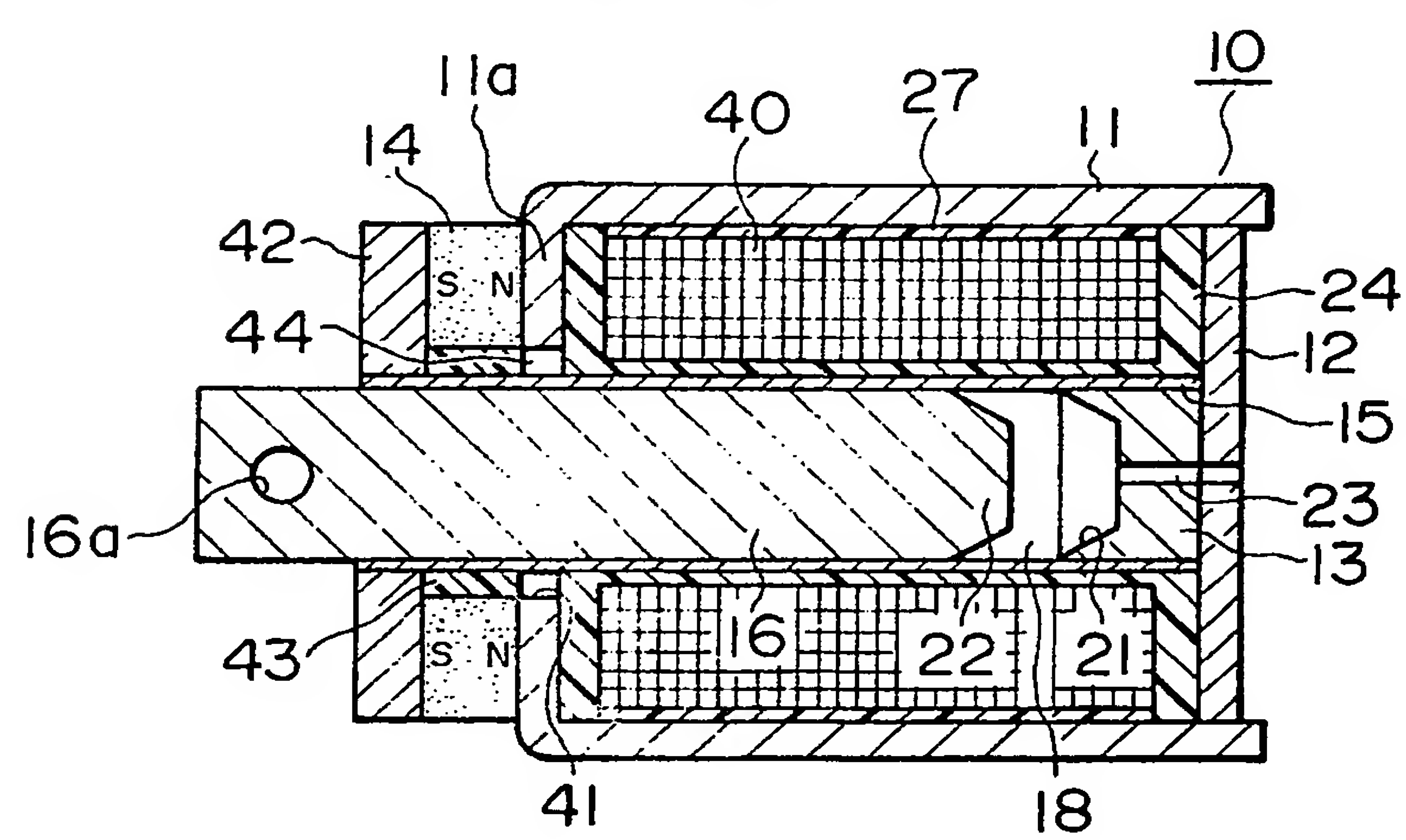

FIG. 4

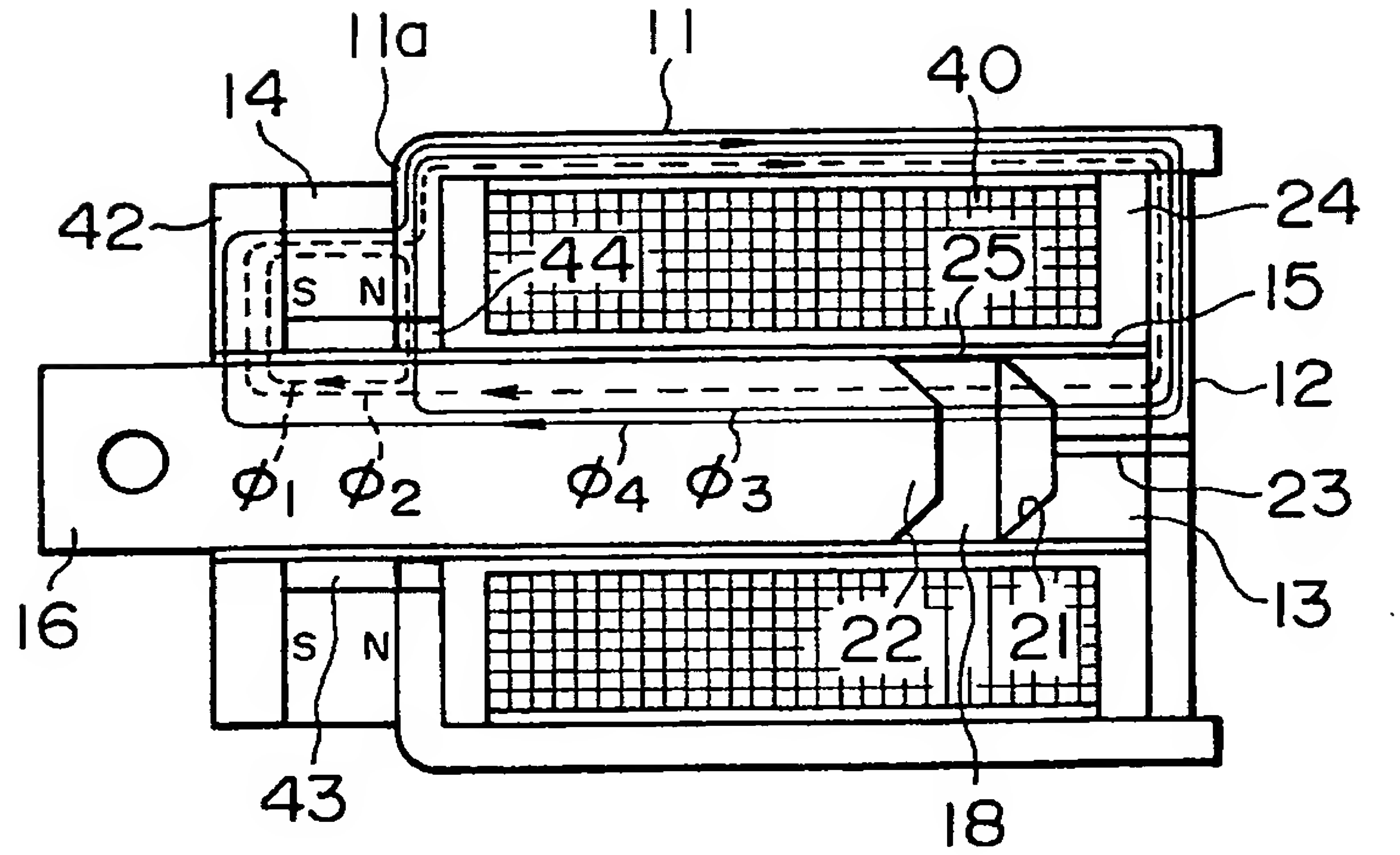

FIG. 5

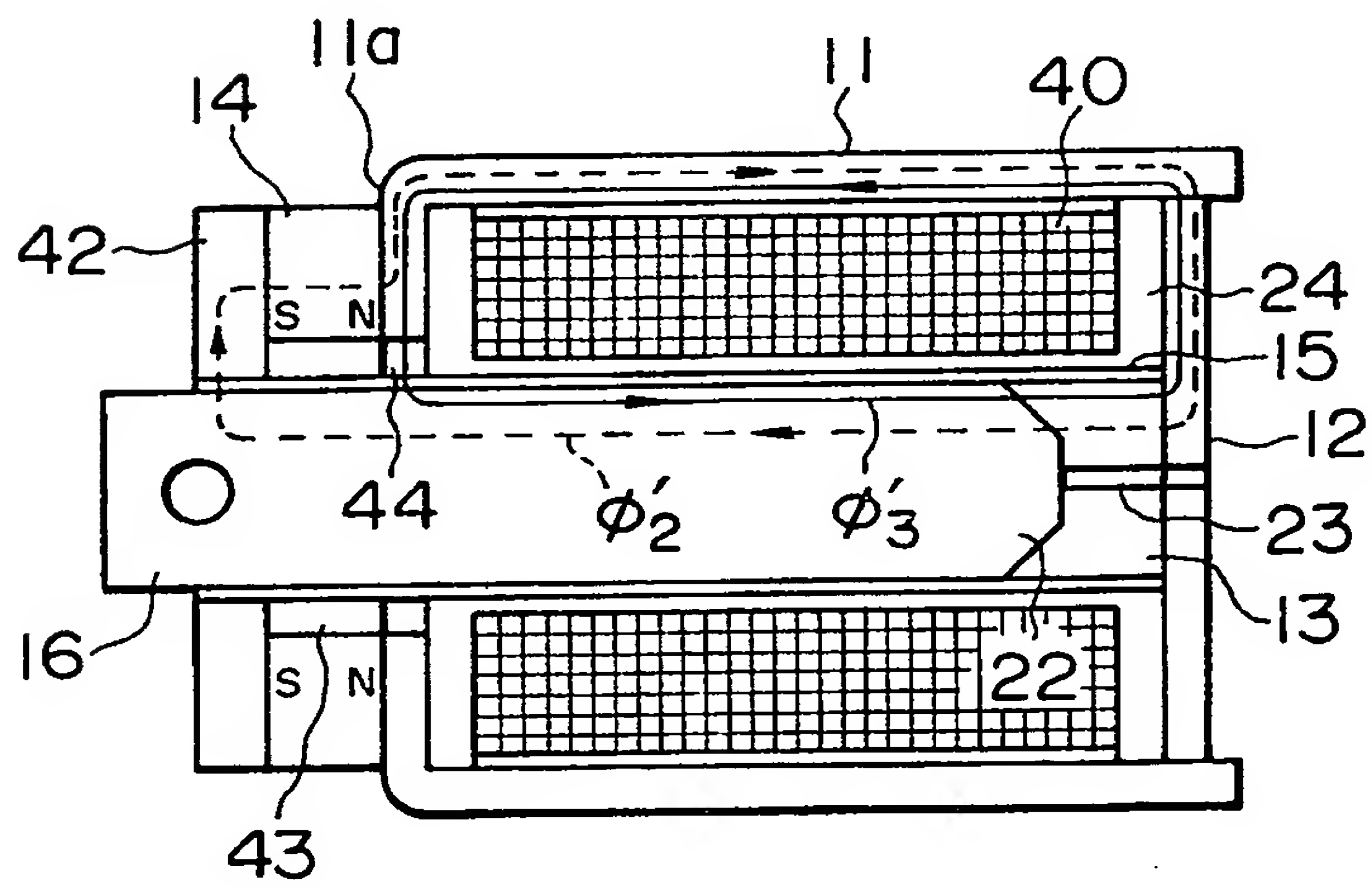

FIG. 6

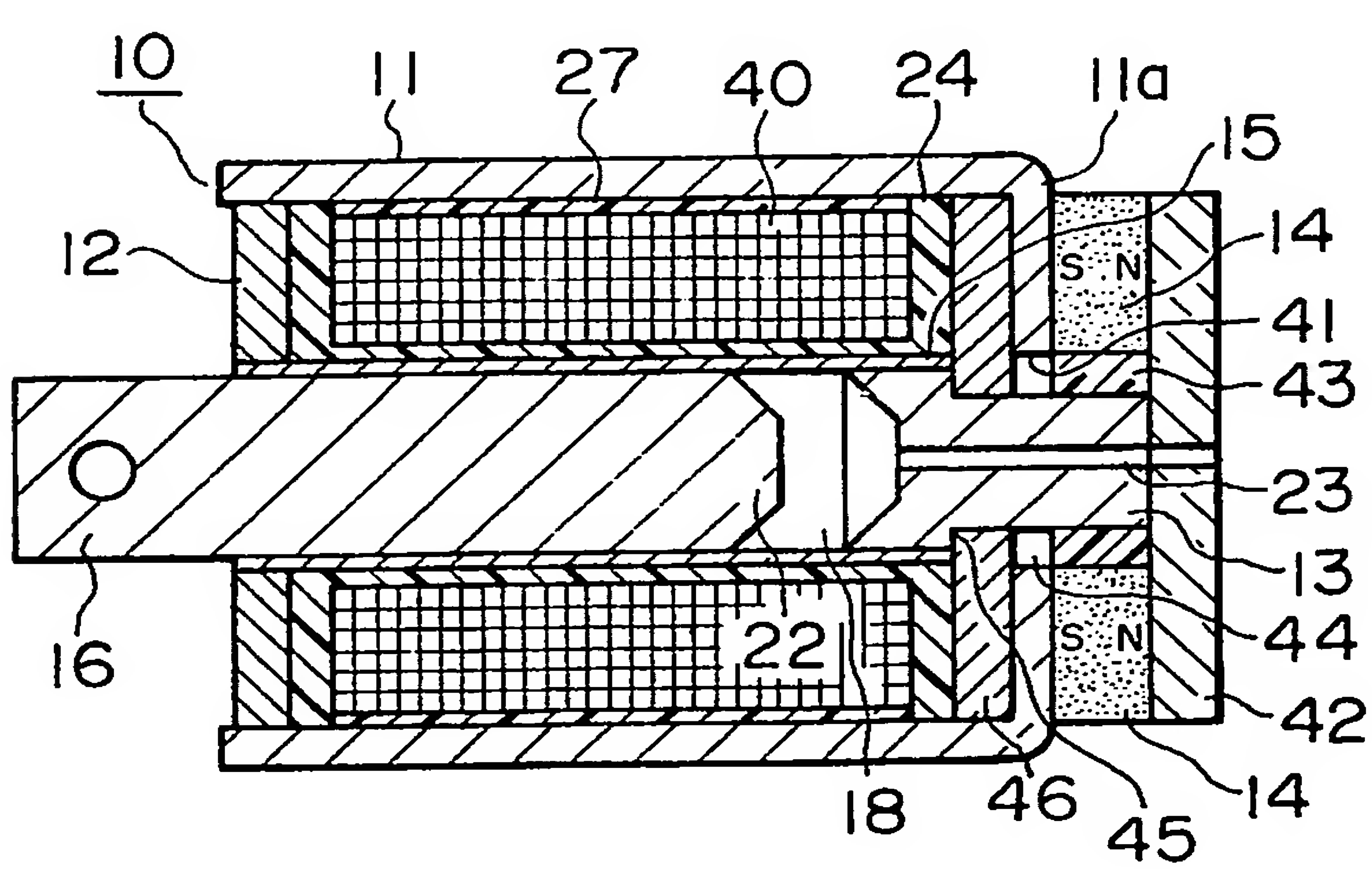

FIG. 7

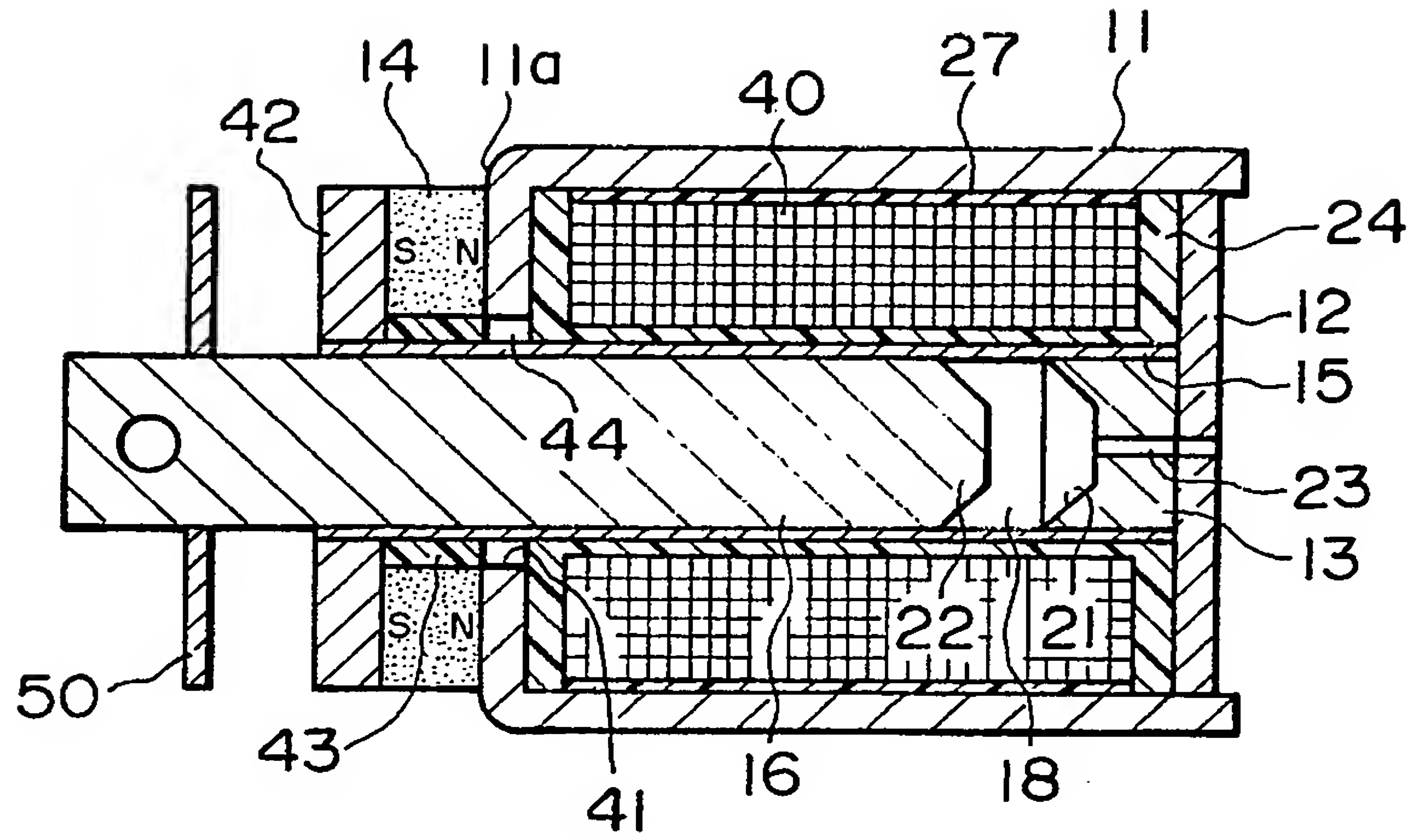

FIG. 8

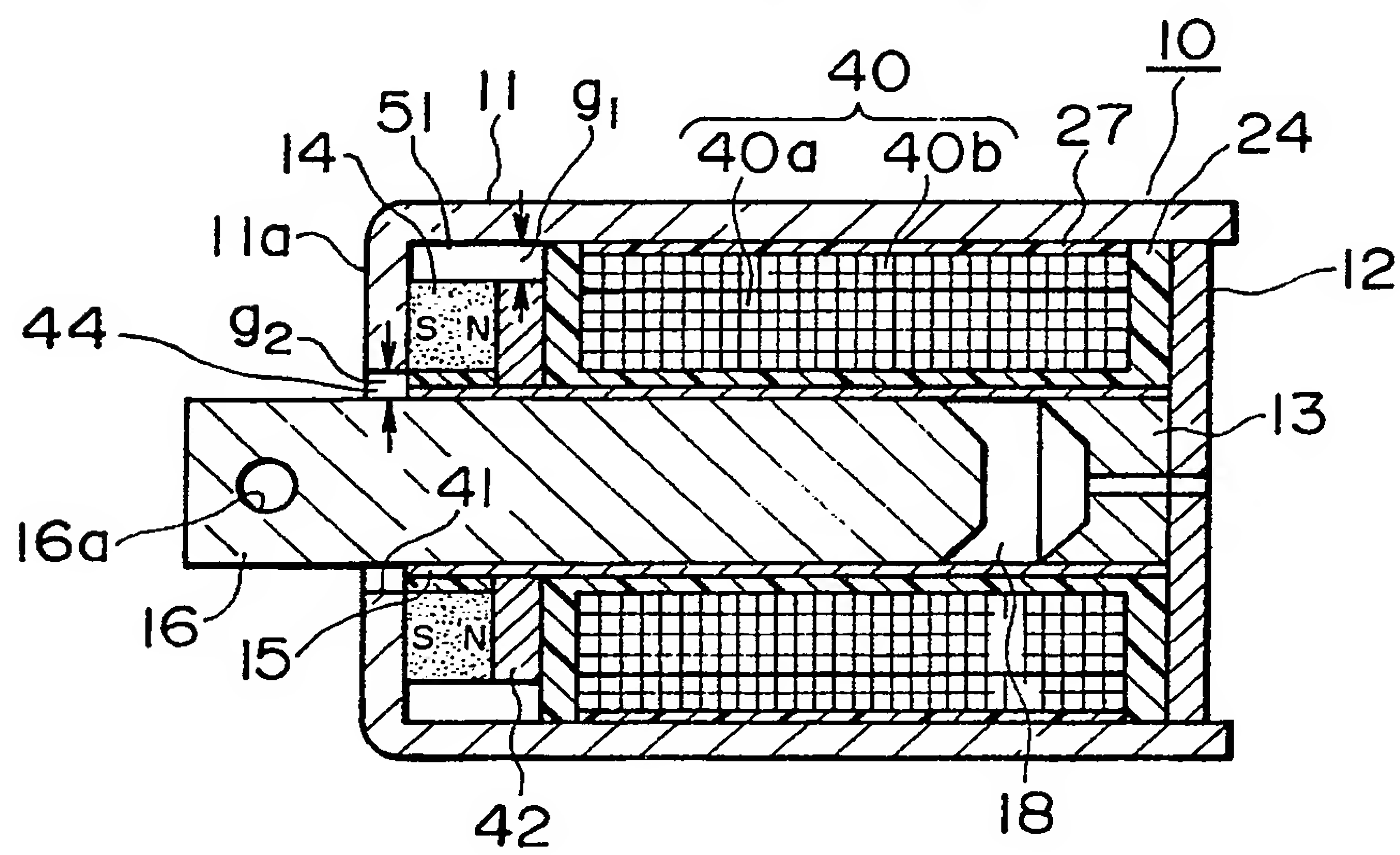

FIG. 9

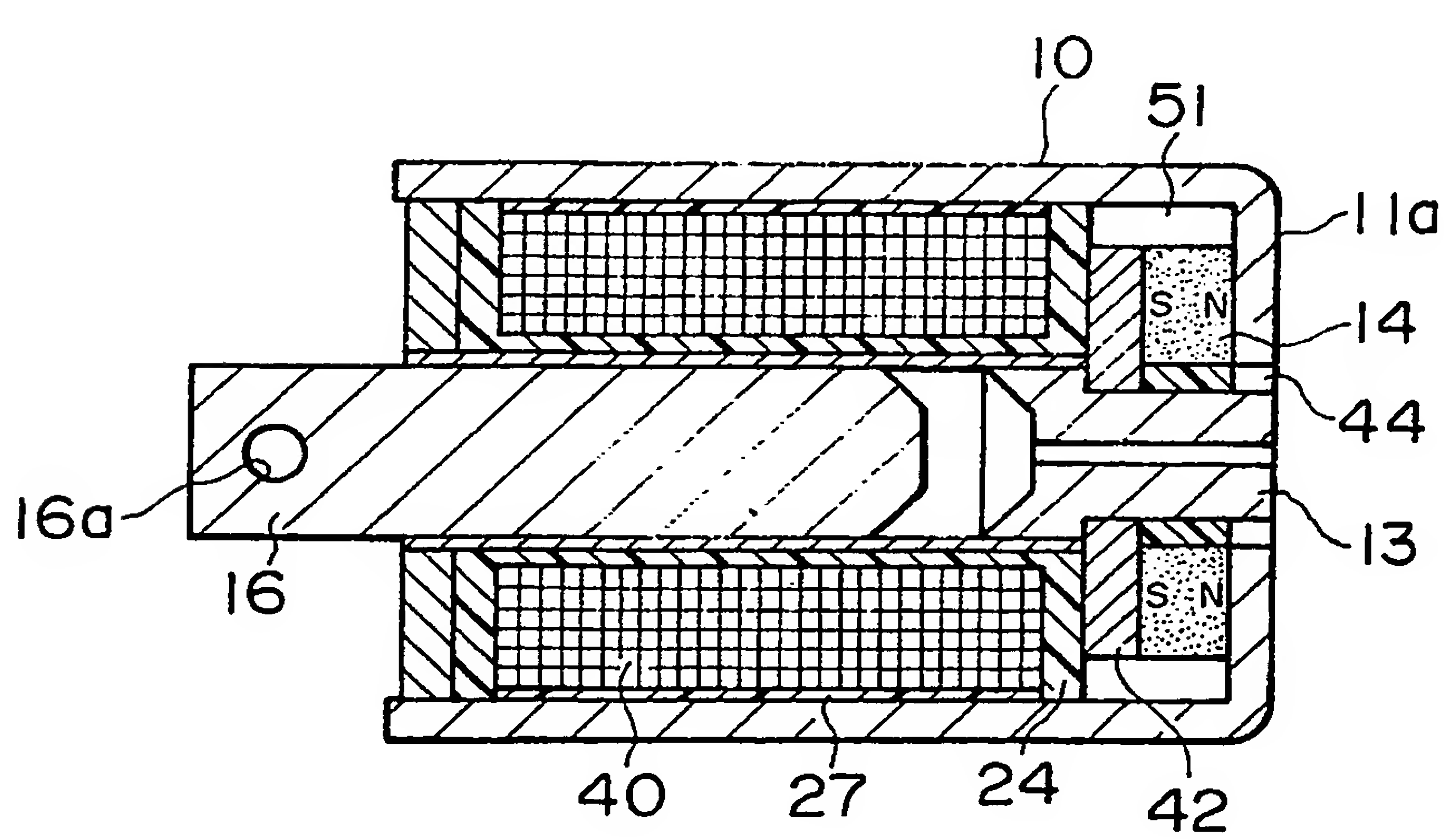

FIG. 10

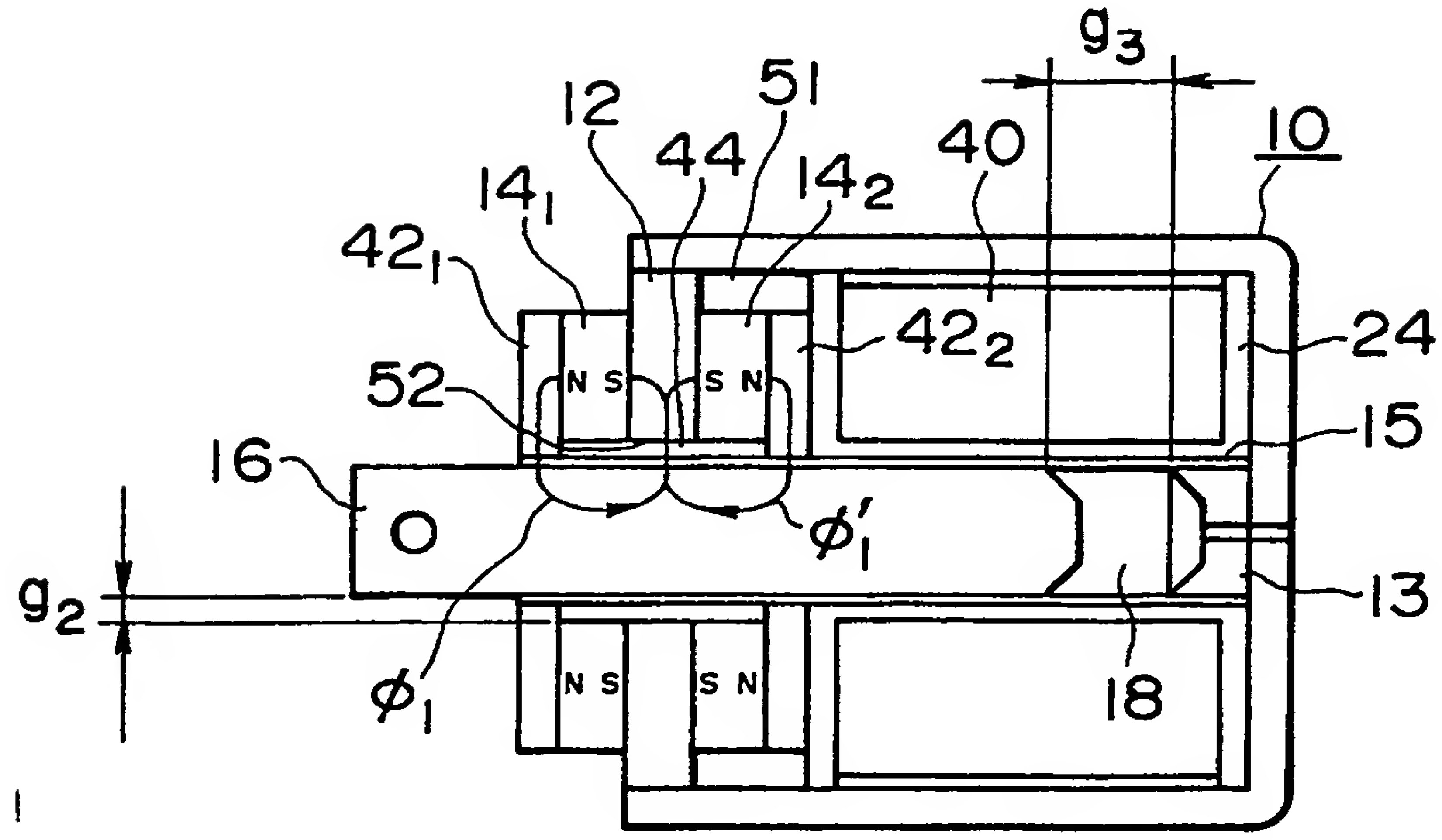

FIG. 11

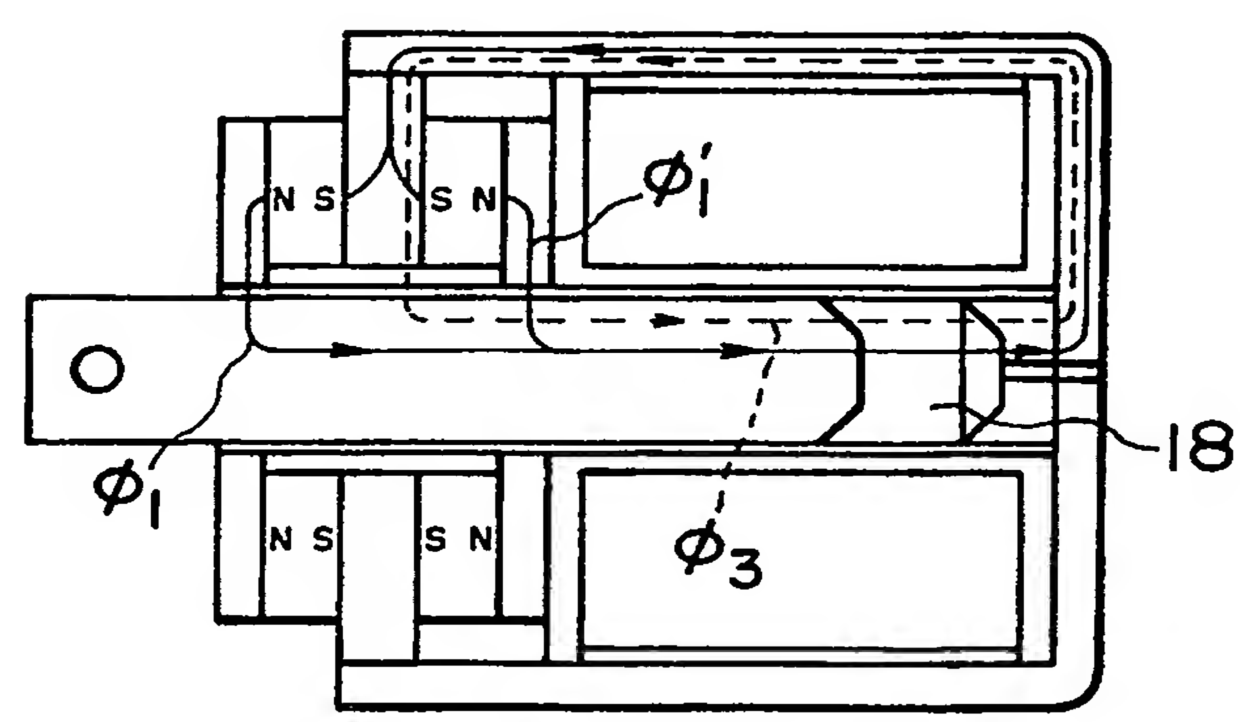

FIG. 12

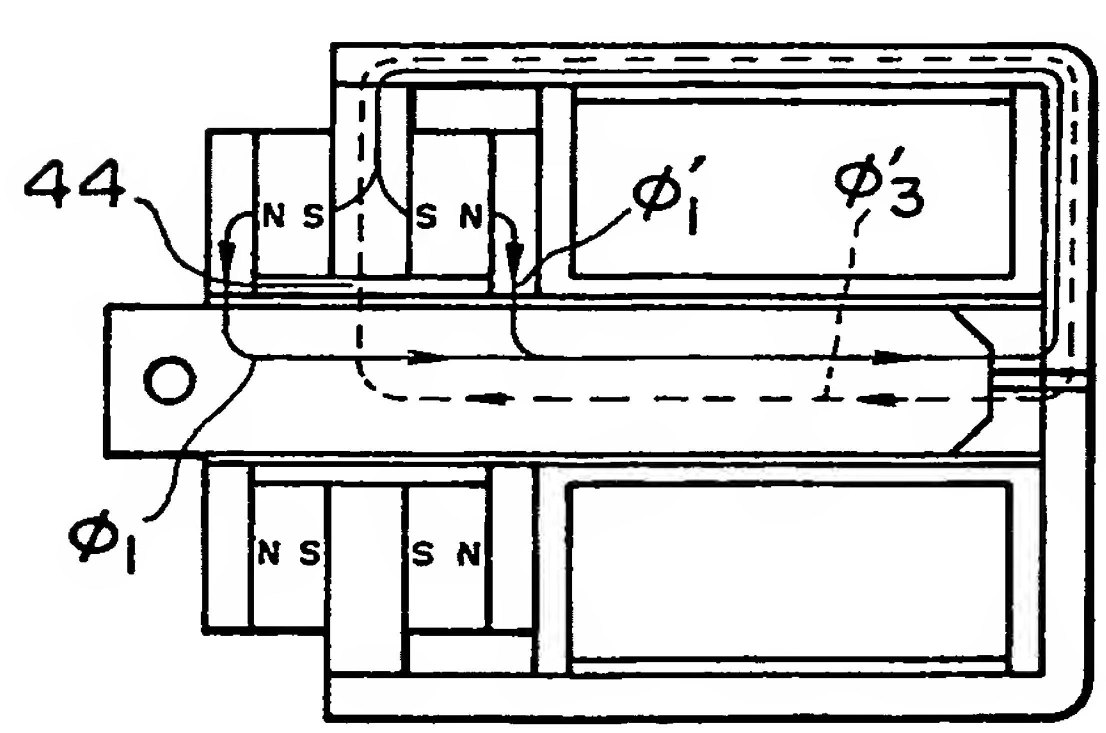

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FIG. 13

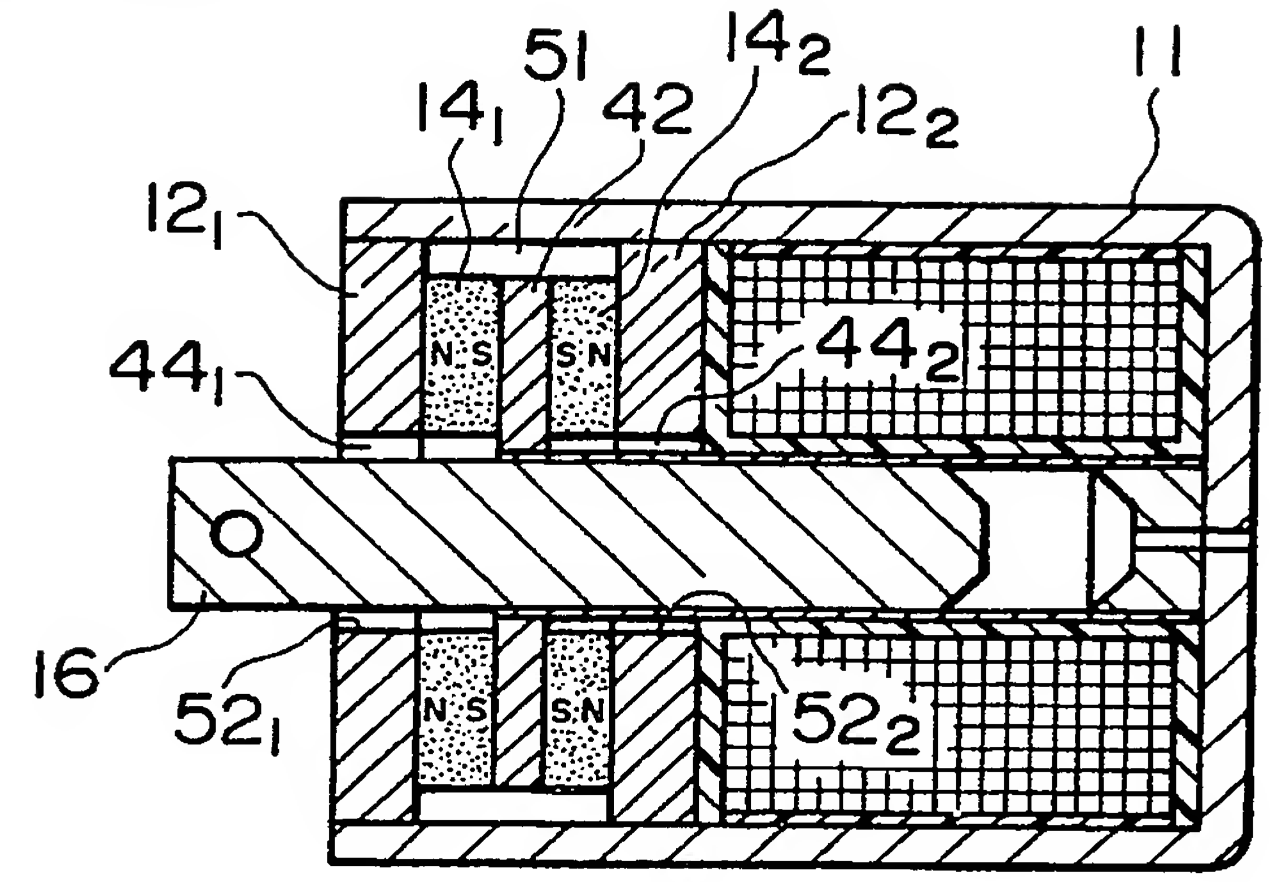

FIG. 14

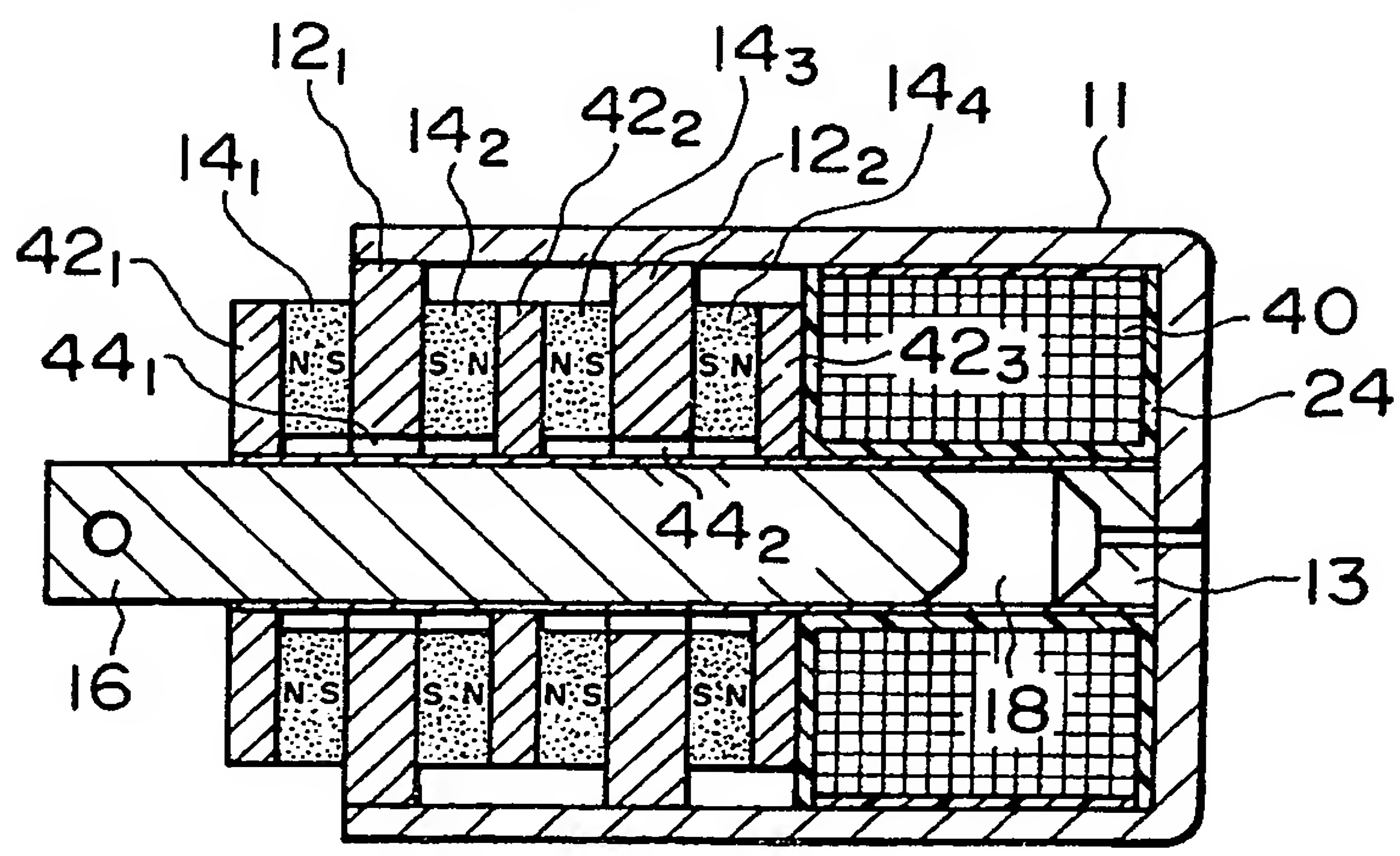

FIG. 15

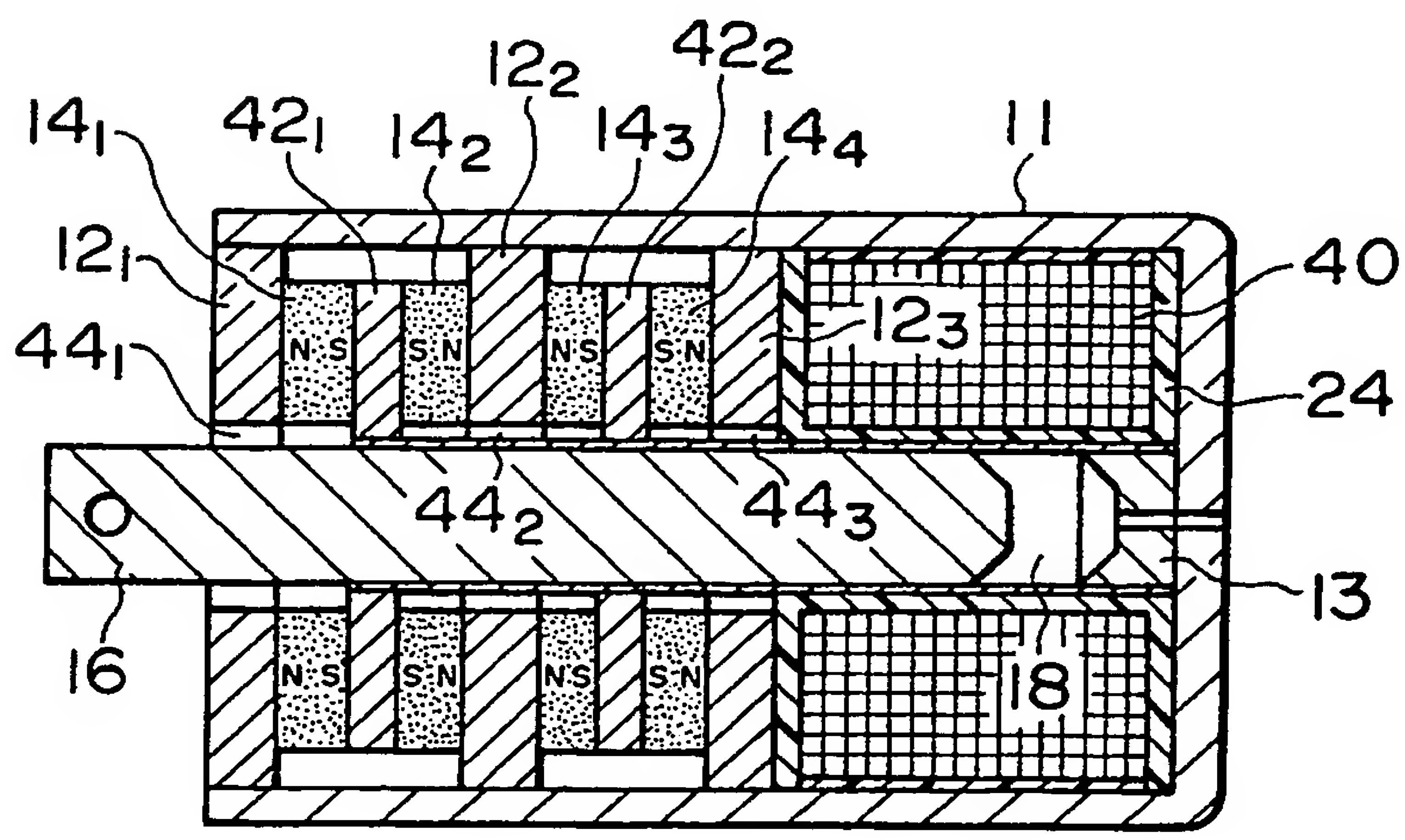

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FIG. 16

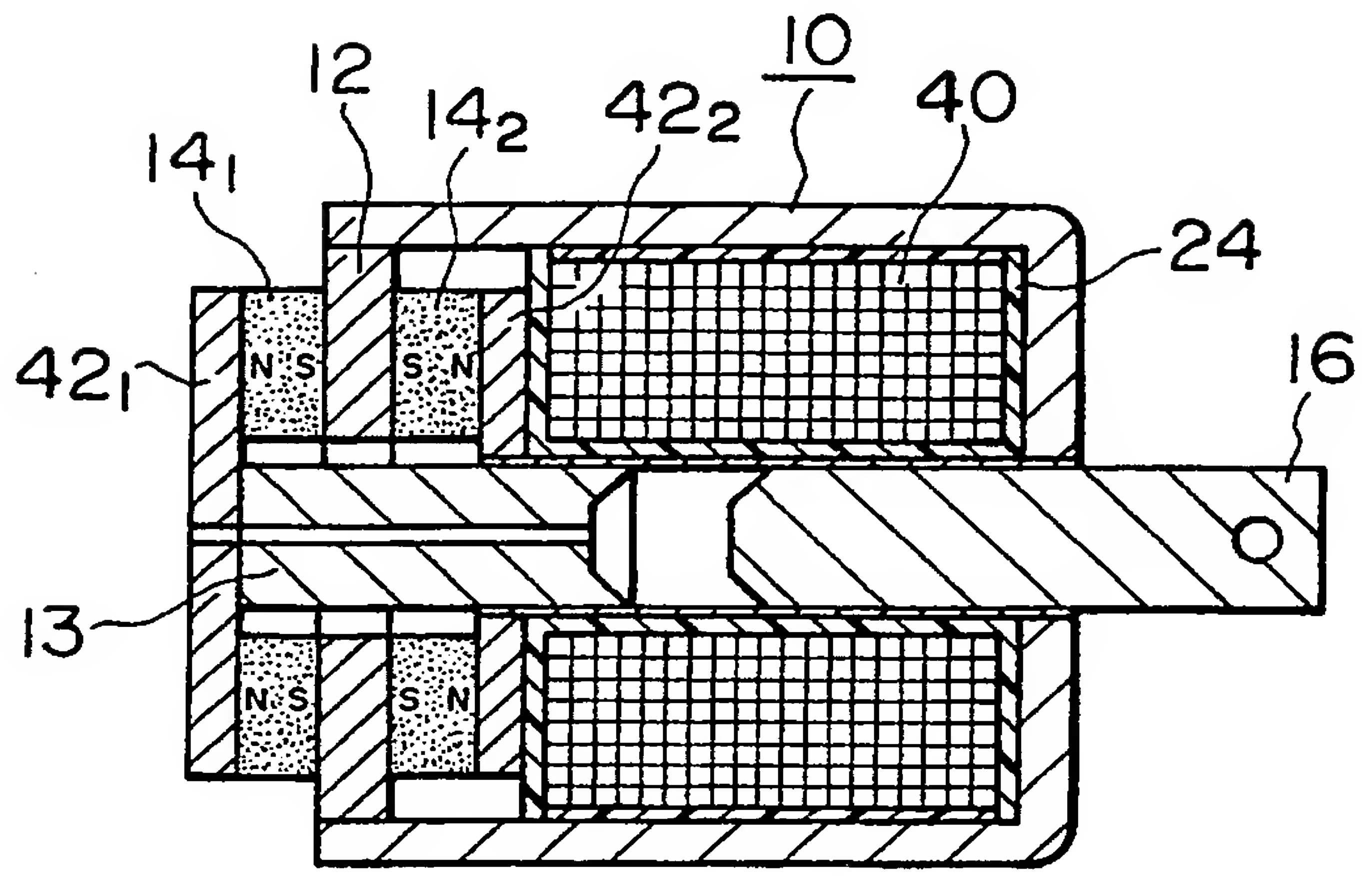


FIG. 17

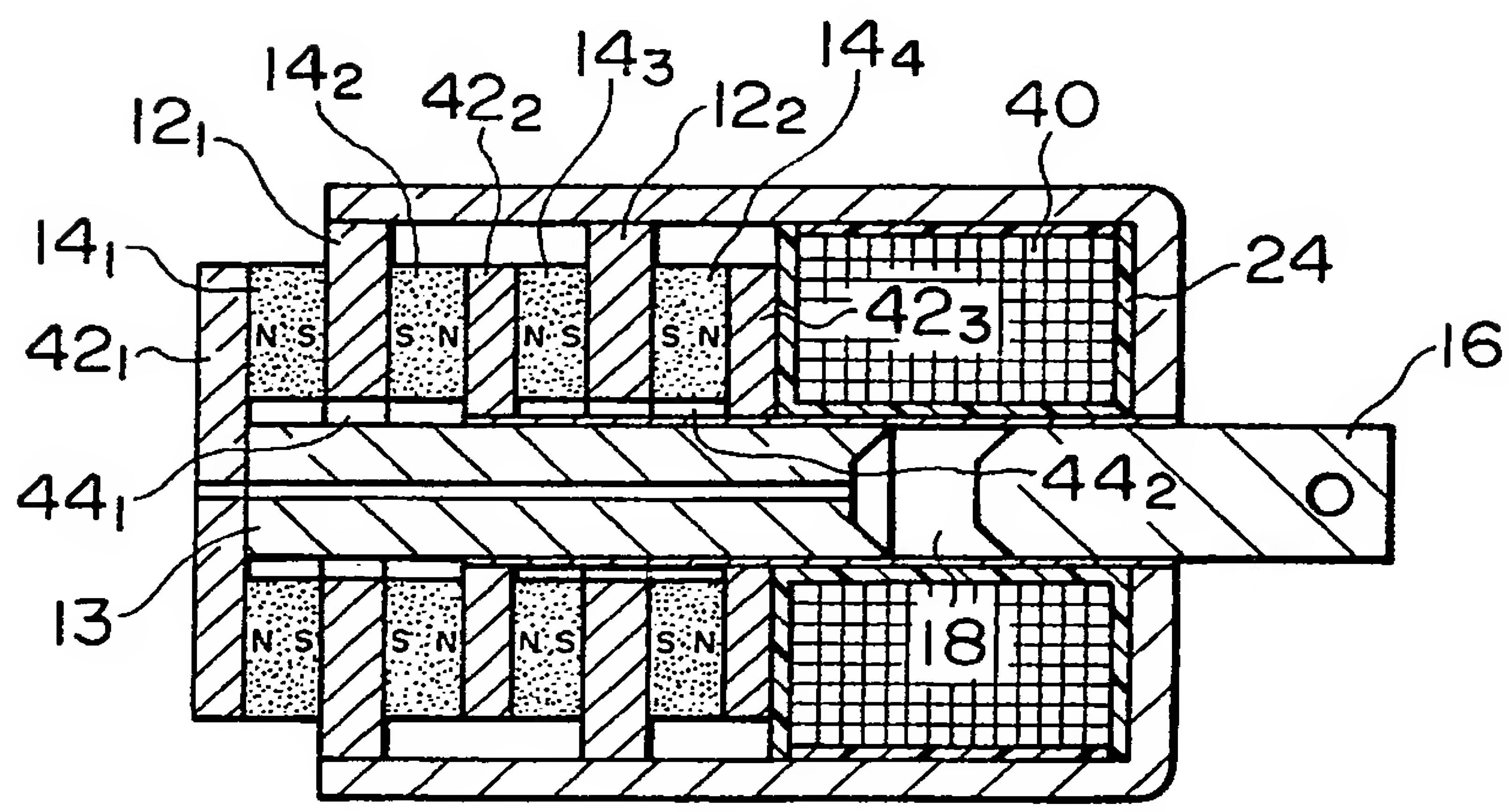


FIG. 18

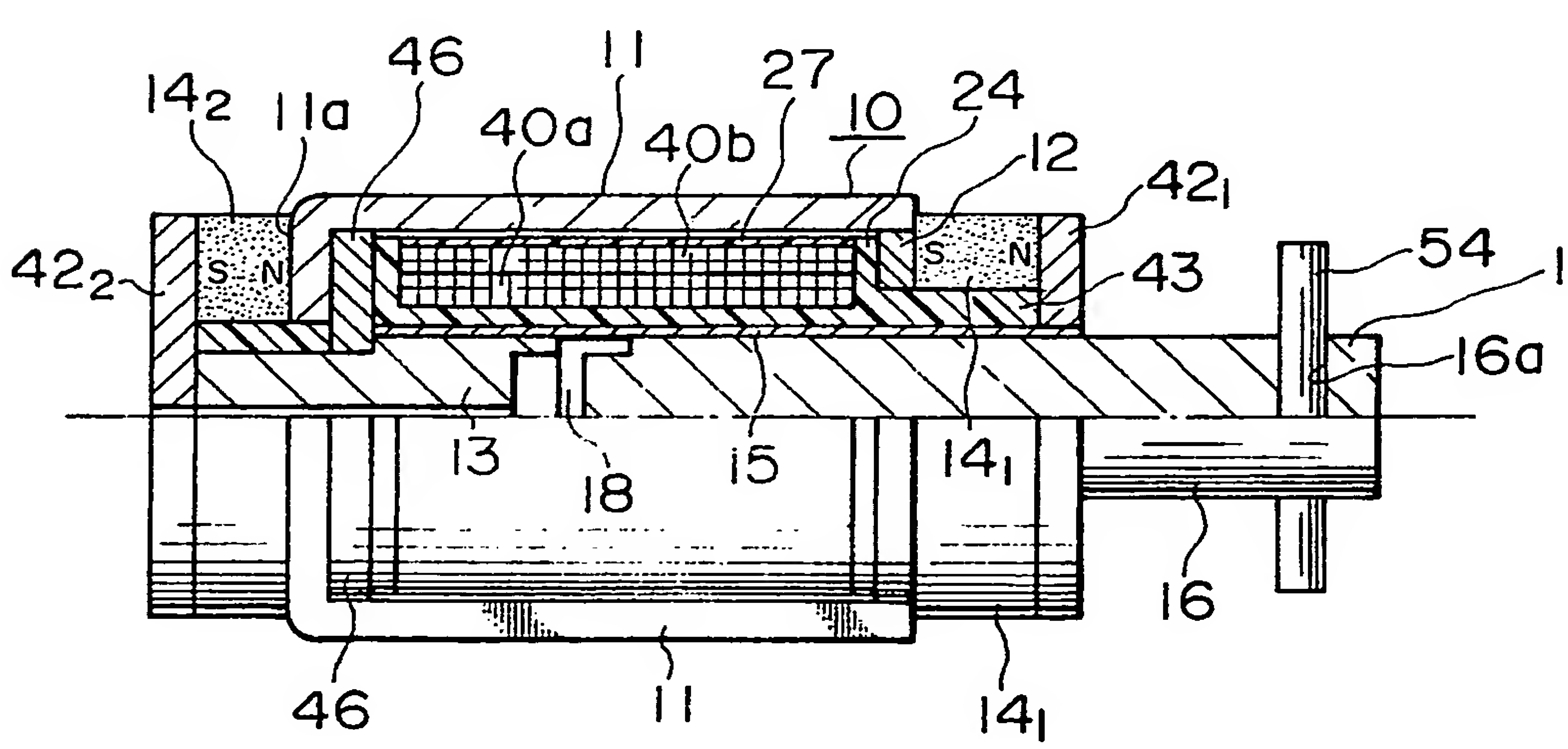
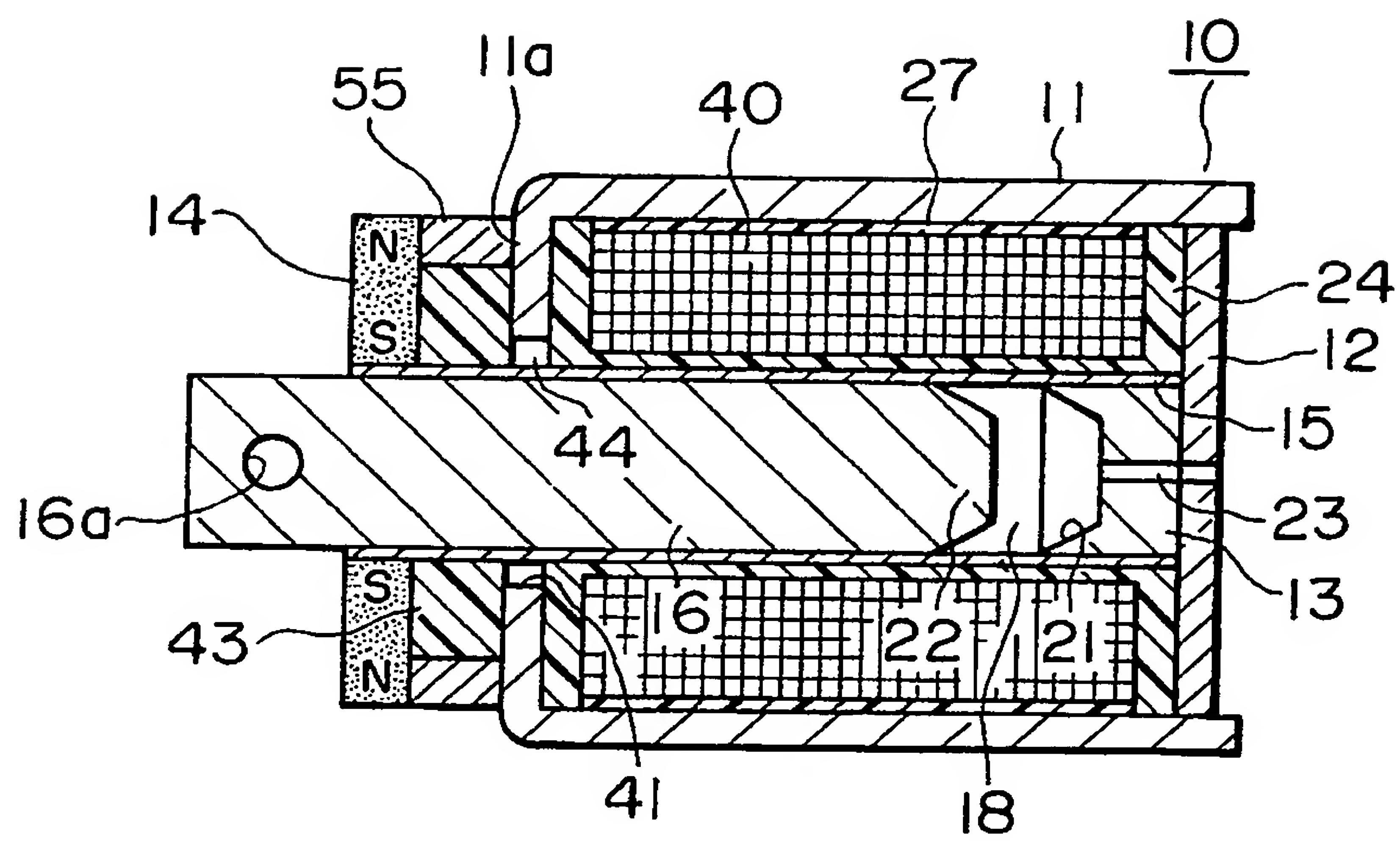


FIG. 19



SPECIFICATION

Self-sustaining solenoid

The present invention relates to a self-sustaining solenoid which moves an armature by the application of an operating current and retains the armature in its moved position even if the operating current is cut off.

A self-sustaining solenoid of the type has been proposed in which an armature is moved into contact with a fixed stop in the form of a permanent magnet, by the application of an operating current to thereby ensure that the armature is retained in its operative position even if the operating current is cut off. With this construction in its released state in which the armature is out of contact with the magnet, the armature is still exposed to the attraction force of the permanent magnet. Accordingly, there is the possibility that the armature may be moved due to external vibration or shock to the operative position in the absence of operating current. If the distance between the armature and the magnet is increased or if a strong return spring is provided for the armature with a view to prevent such an erroneous operation, then the operating current must be increased and as a result the operating power is increased and the solenoid structure inevitably becomes bulky.

A solution to such problems is disclosed in U.S. Patent No. 4,306,207 entitled "Self-Sustaining Solenoid", issued on December 15, 1981. In the self-sustaining solenoid set forth in this patent, an armature is divided into two in the direction of its movement and a permanet magnet is interposed therebetween and, as the permanent magnet, use is made of a magnet that is readily magnetized and demagnetized at room temperature. Applying an operating current to a coil of the self-sustaining solenoid, the armature is moved by magnetic flux produced by the operating current into contact with a fixed stop or core, and, at the same time, the permanent magnet is magnetized by the magnetic flux, so that even if the operating current is cut off, the armature is retained in its operative position by the permanent magnet. When a release current is applied to the coil to return the armature to its initial position, a magnetic field is set up by the current, and the permanent magnet is demagnetized, permitting the armature to be returned to its original position by a small returning force. In addition, since the permanent magnet is demagnetized, it does not act to attract the armature and, therefore, there is no fear of erroneous operation.

The self-sustaining solenoid proposed in the abovesaid U.S. patent is complex in construction because of the provision of the permanent magnet in the armature and has to be mechanically strong because the armature repeatedly strikes against the core. The split structure of the armature is undesirable. Furthermore, as the permanent magnet is demagnetized in the released state, it is necessary that during operation the armature be attracted only by the magnetic flux resulting from the application of the operating current. To return the armature to its original position, the permanent magnet has to be demagnetized and so that the release current is also large, resulting in larger power consumption.

It is an object of the present invention to provide a self-sustaining solenoid in which the possibility of erroneous operation is minimised and the power consumption reduced.

Another object of the present invention is to provide a self-sustaining solenoid which employs a simple-structured armature and hence is mechanically strong.

In accordance with the invention a self-sustaining solenoid is provided with operating and release coil means supplied in use, with an operating or a release current; an armature disposed in the operating and release coil means substantially coaxially therewith in a manner to be movable along the axis thereof, one end of the armature projecting out from one end of the coil means; a magnetizable core disposed in the operating and release coil means at one end thereof, and magnetic yoke means provided on the outside of the operating and release coil means to extend between the core and the peripheral surface of that portion of the armature for magnetic connection therebetween, permanent magnet means disposed near at least one magnetic connecting portion disposed between the magnetic yoke means and the armature or between the magnetic yoke means and the core in such a manner that one of the magnetic poles of the permanent magnet means is magnetically connected to the magnetic yoke means and the other pole of the permanent magnet means is magnetically connected to the armature and/or the core on which side the permanent magnet means is disposed, the magnetic fluxes emanating from the permanent magnet means being mostly confined within a closed magnetic path running through the armature, the core and the magnetic yoke means when the armature is in contact with the core; and magnetic gap means provided in at least one of the magnetic connecting portions between the ends of the magnetic yoke means and the armature and the core on which side the permanent magnet means is disposed, the magnetic gap means having a size smaller than the distance between the armature and the core when the armature is in its released position spaced from the core and being so designed as to permit the passage therethrough of most of the magnetic fluxes of the permanent magnet means when the armature is held at its released position.

In the accompanying drawings:-

Figure 1 is a sectional view showing a conventional self-sustaining solenoid;

Figures 2A and *2B* are diagrams showing the relationship between magnetic fields set up by coil currents and magnetization of a permanent magnet in Figure 1;

Figure 3 is a sectional view illustrating an embodiment of the self-sustaining solenoid in accordance with the invention in which a permanent magnet is provided on the side of the projecting end of a moving iron core;

Figure 4 is a schematic diagram showing the path of magnetic flux from the permanent magnet in the

released state and the path of magnetic flux produced by a release current in the embodiment of Figure 3;

Figure 5 is a schematic diagram showing the path of magnetic flux from the permanent magnet in the operative state and the path of magnetic flux produced by an operating current in the embodiment of Figure 3;

Figure 6 is a sectional view illustrating another embodiment of a self-sustaining solenoid in accordance with the invention in which the permanent magnet is provided on the side of a core;

Figure 7 is a sectional view illustrating a modified form of the embodiment of Figure 3;

Figure 8 is a sectional view illustrating another modification of the embodiment of Figure 3 in which the permanent magnet is disposed on the inside of the magnetic yoke;

Figure 9 is a sectional view illustrating a modified form of the embodiment of Figure 6 in which the permanent magnet is disposed on the inside of the magnetic yoke;

Figure 10 is a sectional view illustrating another embodiment of self-sustaining solenoid in which a plurality of permanent magnets are provided on the side of the projecting end of the moving iron core;

Figure 11 is a diagram showing a magnetic path of magnetic flux from the permanent magnets in the released state and a magnetic path of magnetic flux produced by an operating current in the embodiment of Figure 10;

Figure 12 is a diagram showing a magnetic path of the magnetic flux from the permanent magnets in the operative state and a magnetic path of magnetic flux produced by a release current in the embodiment of Figure 10;

Figure 13 is a sectional view illustrating a modified form of the embodiment of Figure 10;

Figure 14 is a sectional view illustrating another modification of the embodiment of Figure 10 in which the number of prmanent magnets used is increased;

Figure 15 is a sectional view illustrating a modification of the embodiment of Figure 13 in which the number of permanent magnets used is increased;

Figure 16 is a sectional view illustrating another embodiment of a self-sustaining solenoid in which a plurality of permanent magnets are provided on the side of the fixed stop;

Figure 17 is a sectional view illustrating a modified form of the embodiment of Figure 16 in which the number of permanent magnets used is increased;

Figure 18 is a front view, partly in section, illustrating another embodiment of a self-sustaining solenoid in which pluralities of permanent magnets are provided on the side of the projecting end of the moving iron core and on the side of the fixed receiver; and

Figure 19 is a sectional view illustrating another modification of the embodiment of Figure 3, where the permanent magnet has magnetization in a radial direction.

To facilitate a better understanding of the present invention, a description will be given first, with reference to Figure 1, of a conventional self-sustaining solenoid. A magnetic yoke 10 comprises a magnetic yoke proper 11 produced by bending a plate formed from magnetizable material into a U-shaped form and a coupling portion 12 is attached to the yoke proper 11 in a manner to interconnect its end portions. A substantially cylindrical fixed stop or core 13 is attached to an intermediate portion 11a of the magnetic yoke proper 11 centrally thereof. For this puspose, a hole 11e is made in the intermediate portion 11a centrally threof and a support portion 20 projects out from the core 13 centrally thereof on the side of the intermediate portion 11a and is inserted into the hole 11e. The projecting portion of the support portion 20 is spread out in its radial direction, by which the fixed core 13 is staked to the intermediate portion 11a. A narrow passage 23 is made in the core 13 and extends along its axis, permitting the passage therethrough of air into and out of a gap 18 during movement of a moving iron core 16.

One end portion of a cylindrical member 15 of non-magnetic material such, for instance, as brass, surround the core 13, and the other end portion of the cylindrical member 15 is inserted into a centrally-disposed hole in the coupling portion 12 of the magnetic yoke. A cylindrical moving iron armature 16 of substantially the same diameter as the fixed receiver 13 is inserted into the cylindrical member 15 in a manner to be slidable along the axis thereof. When the self-sustaining solenoid is in its inoperative state, the armature 16 defines the air gap 18 betweeen its inner end and the core 13 and it projects out at the other end from the magnetic yoke 10.

The armature 16 is divided into two in its lengthwise direction, and the two parts are interconnected by a permanent magnet 14 having a small coercive force. The permanent magnet 14 is magnetized, at room temperature, by a magnetic field emanating from a coil of the self sustaining solenoid during attraction and is readily demagnetized by a magnetic field reverse in direction from the above-said magnetic field, and this permanent magnet can repeatedly be magnetized and demagnetized. The projecting end of the armature 16 has made therein a through hole 16a for connection to a load.

The end face of the armature 16 on the side of the core 13 has a projection 22 formed integrally therewith to have trapezoidal cross section including the axis of the armature 16. In the end face of the core 13 is formed a complementary recess 21 for receiving the projection 22. With such an arrangement, the oppositing area between the armature 16 and the core 13 is increased, making it possible to increase the attraction force between the core and the armature. A bobbin 24 of a non-magnetic material such, for intance, as a synthetic resin material, is mounted on the cylindrical member 15. An operating coil 25 is wound on the bobbin 24, and a release coil 26 is further wound on the operating coil 25. A tape 27 is wrapped around the release coil 26.

When a current is supplied to the operating coil 25 to attract the moving iron core 16, a magnetic flux B_1 is set up in the cylindrical member 15 substantially parallel to the axis thereof. The magnetic flux B_1

passes through a closed magnetic path consisting of the magnetic yoke 10, the core 13 and the armature 16 and, the force created by the magnetic flux acts upon the armature 16 to move it toward the core 13. Moreover, the magnetic flux B_1 magnetizes the permanent magnet 14 and even when the operating current is cut off, the permanent magnet 14 remains magnetized as shown in Figure 2A and, by its magnetic flux B_0, the armature 16 is held against the stop 13.

In order to return the armature 16 to its initial or inoperative position, a release current is supplied to the release coil 26, by which there is established in the cylindrical member 15 a magnetic flux B_2 substantially parallel to the axis thereof but opposite in direction to the aforesaid magnetic flux B_1. As illustrated in Figure 2B, the magnetic flux B_2 is opposite in direction to the magnetic flux B_0 of the permanent magnet 14, and hence the permanent magnet 14 is demagnetized. Accordingly, the armature can be returned to its initial position by means of a return spring, even if the spring is very weak. In this example, if the solenoid were used with the direction of movement of the armature 16 held downward, then the armature would return to its original position by its own weight or a load coupled therewith, so no return spring would be needed.

The solenoid depicted in Figure 1 consumes less power and is more stable than in the case where the core 13 is formed by a permanent magnet which is not demagnetized by the magnetic fields of the coils 25 and 26. In this case, however, since the permanent magnet 14 is interposed between the divided portions of the armature 16, it is difficult to construct such a small solenoid in which the moving iron core 16 is about 4mm in diameter and about 15 mm long. Further, since the armture 16 repeatedly strikes against the core 13, the permanent magnet 14 is also exposed to considerably impact forces and it is difficult to construct a solenoid of sufficient mechanical strength. Moreover, as the permanent magnet 14 is repeatedly magnetized and demagnetized, power comsumption is relatively large for each operation. In addition, during operation, the permanent magnet 14 does not contribute at all to the movement of the armature 16 and it is attracted only by the magnetic flux emanating from the operating coil 25.

Figure 3 illustrates an embodiment of the self-sustaining solenoid in accordance with the present invention. In Figure 3, the parts corresponding to those in Figure 1 are identified by the same reference numerals. In this embodiment the permanent magnet 14 is mounted on the magnetic yoke 10 on the side of the projecting end of the armature 16. The armature 16 projects out from the intermediate portion 11a of the magnetic yoke proper 11 and the fixed core 13 is secured to the coupling portion 12. An opening 41 of a diameter a little larger than the outer diameter of the armature 15 is made in the intermediate portion 11a of the magnetic yoke proper 11 centrally thereof, and the armature 15 of a non-magnetic material is disposed in the magnetic yoke proper 11 so that it projects out therefrom through the opening 41. The permanent magnet 14 is of annular configuration, for example and is fixed to the intermediate portion 11a of the magnetic yoke proper 11 around the end portion of the armature 15 projecting through the opening 41. A magnetic path for the magnetic flux of the permanent magnet 14, has a magnetic gap 44 smaller than the gap 18 defined between the armature 16 in its released state, and the core 13. With this the magnetic flux of the permanent magnet 14 is prevented from passing through the magnetic gap 44 when the armature 16 is in direct contact with the core 13. An annular magnetic yoke 42 is fixed to the outer end face of the permanent magnet 14 around the armature 15. A gap is defined between the inner peripheral surface of the permanent magnet 14 and the outer peripheral surface of the armature 15, and the magnetic gap 44 of the same as or smaller than this gap is defined between the inner peripheral surface of the opening 41 and the outer peripheral surface of the moving iron core 16. A ring-shaped spacer 43 of a non-magnetic material, such as brass is inserted between the armature 15 and the permanent magnet 14 as required. The spacer 43 may also be extended to fill up the magnetic gap 44. The permanent magnet 14, is formed for instance, as a ferrite magnet, a rare earth magnet or the like having relatively high coercive force. In Figure 3, the permanent magnet 14 has its north and south poles on the side of the intermediate portion 11a and on the side of the magnetic yoke 42, respectively. Furthermore, in this embodiment, only one coil 40 is wound on the bobbin 24.

As illustrated in Figure 4, when the armature 16 and the core 13 are spaced apart, the magnetic fluxes emanating from the permanent magnet 14 set up two closed magnetic paths in the solenoid. That is to say, a first closed magnetic path is formed via a route (magnetic pole N - intermediate portion 11a - gap 44 - core 15 - armature 16 - core 15 - magnetic yoke 42 - magnetic pole S], and a flux ϕ_1 flows in this path. A second closed magnetic path is formed via a route [magnetic pole N - intermediate portion 11a - magnetic yoke proper 11 - coupling portion 12 - core 13 - gap 18 - armature 16 - core 15 - magnetic yoke 42 - magnetic pole S], and a magnetic flux ϕ_2 flows in this path. In the second closed magnetic path, as the reluctance of the gap 18 is markedly higher than in the gap 44, the magnetic flux ϕ_2 confined in the second closed magnetic path is appreciably smaller than the magnetic flux ϕ_1 confined in the first closed magnetic path. It approximately holds true that $\phi_1 + \phi_2 = \phi_M$ the latter being the total flux obtained from the permanent magnet 14 and is substantially constant. Consequently, in the state in which neither operating or release current is applied to coil 40, the armature 16 would not be moved by the flux in the second closed magnetic path becuase the magnetic flux ϕ_2 is small in quantity. Owing to the magnetic energy of the first closed magnetic path, the moving iron core 16 attempts to remain there when external force is applied thereto.

When operating current is supplied to the coil 40 so that the direction of the magnetic flux in the core 16 produced by the coil 40 coincides with that of the flux ϕ_2 from the magnet 14, the magnetic fluxes

yielded by the operating current form two closed magnetic paths in the solenoid. That is to say, a third closed magnetic path is formed via a route [intermediate portion 11a - magnetic yoke proper 11 - coupling portion 12 - core 13 - gap 18 - armature 16 - cylindrical member 15 - gap 44 - intermediate portion 11a], an a magnetic flux $\varnothing_3$ flows in the third closes magnetic path. A fourth closed magnetic path is formed via a route [magnetic pole N - intermediate portion 11a - magnetic yoke proper 11 - coupling portion 12 - core 13 - gap 18 - armature 16 - cylindrical member 15 - magnetic yoke 42 - magnetic pole S], and a magnetic flux $\varnothing_4$ flows in the fourth closed magnetic path.

In that portion of the armature 16 which remains in the coil 40, magnetic fluxes $\varnothing_2 + \varnothing_3 + \varnothing_4$ flow along the axis thereof during the application of the operating current. By these magnetic fluxes, the armature 16 is subjected to a force which moves it towards the core 13. In this case, the magnetic fluxes $\varnothing_1$ and $\varnothing_3$ are opposite in direction in the gap 44. Therefore, when the flux $\varnothing_3$ becomes larger than the flux $\varnothing_1$, the flux $\varnothing_1$ is forced to take the second closed magnetic path. Consequently, the force applied to the armature 16 becomes larger than in the case where it is exposed only to the magnetic flux emanating from the coil 40. In this way, the armature 16 is moved towards the core 13 by the flux in the second, third and fourth closed magnetic paths, resulting in the projection 22 being snugly located in the trapezoidal recess 21. In this stage, as the gap 18 does not exist, the reluctance of the second closed magnetic path is far smaller than in the case where the armature 16 and core 13 are not in contact with each other. Accordingly, the flux $\varnothing_2'$ which is confined in the second closed magnetic path as shown in Figure 5 becomes far larger than the magnetic flux $\varnothing_2$. In contrast thereto, since the reluctance of the first closed magnetic path increases faster than the reluctance of the second closed magnetic path by virtue of the presence of the gap 44, substantially no magnetic fluxes flow in the first closed magnetic path. As the value of the magnetic flux $\varnothing_2'$ confined in the second closed magnetic path increases as described above, the armture 16 is held in contact with the core 13 by the force created by the flux flowing in the second closed magnetic path even when the operating current is cut off.

In order to return the armature 16 to its initial position, a release current is applied to the operating and release coil 40 in a direction opposite to the operating current. In this case, as shown in Figure 5, a closed magnetic path is set up via a route [intermediate portion 11a - gap 44 - armature 16 - core 13 - coupling member 12 - magnetic yoke proper 11 - intermediate portion 11a], and a magnetic flux $\varnothing_3'$ is confined in this closed magnetic path. Since the magnetic flux $\varnothing_3'$ is reverse in direction to the magnetic flux $\varnothing_2'$ in the axial direction of the armature 16, and hence it cancels the magnetic flux $\varnothing_2'$ emanating from the permanent magnet 14, by which the force of the permanent magnet 14 attracting the armature 16 is reduced to almost zero, resulting in the armature 16 being capable of being returned by a very weak force. In practice, since the armature is usually brought back to its original position by the aid of a return spring or through utilization of its own weight, the armature 16 can be returned with a lower release current.

In the conventional solenoid depicted in Figure 1, during its return operation the permanent magnet 14 has to be demagnetized, and consequently a relatively larger release current is needed for the return operation. In contrast thereto, according to the solenoid of the present invention, the permanent magnet 14 need not be demagnetized and the armature 16 is returned by applying a relatively small release current to the operating and release coil 40. Moreover, in the solenoid of the present invention, during opration, the magnetic flux of the permanent magnet 14 also acts to attract the armature 16 as described previously, so that the operating current may be smaller than is required in the case of the prior art solenoid shown in Figure 1. For the reasons described above, in a solenoid in accordance with the present invention, the release current as well as the operating current are smaller than those needed in the prior art solenoid and hence the power consumption is small.

Figure 6 illustrates another embodiment of the self-sustaining solenoid of the present invention, in which the parts corresponding to those in Figure 3 are identified by the same reference numerals. In this embodiment the permanent magnet 14 is mounted on the end face of the magnetic yoke 10 on the side of the core 13, and the armature 16 projects out from the coupling member 12 as in the case of Figure 1. On the other hand, the core 13 is extended in its axial direction and the extended portion projects out of the opening 41 of the intermediate portion 11a. The extended portion of the core 13 is reduced in diameter to form a stepped portion 45. Interposed between the intermediate portion 11a and the bobbin 24 is a square-shaped, non-magnetic spacer 46 having a circular hole therein into which the extended portion is inserted to engage its stepped portion 45 with the spacer 46. The magnetic gap 44 is defined between the outer peripheral surface of the opening 41 of the intermediate portion 11a. The circular permanent magnet 14 is mounted on the intermediate portion 11a on the opposite side from the bobbin 24, and the projecting end portion of the core 13 is inserted into the permanent magnet 14, with a gap defined therebetween. A spacer 43 is disposed in the gap as required. The magnetic yoke 42 attached to the outer end face of the permanent magnet 14 is made disc-shaped, and the end face of the core 13 abuts against the magnetic yoke 42. When the armature 16 lies at its outermost position, the main magnetic flux of the permanent magnet 14 sets up a magnetic path via a route [magnetic pole N - magnetic yoke 42 - core 13 - magnetic gap 44 - intermediate portion 11a - magnetic pole S] and does not act on the armature 16. When applying the operating current to the coil 40, magnetic flux is produced which is reverse in direction in the magnetic gap 44 from the magnetic flux emanating from the permanent magnet 14. Consequently, the magnetic flux from the permanent magnet 14 diverts into a magnetic path via a route [magnetic pole N -

magnetic yoke 42 - core 13 - gap 18 - armature 16 - coupling member 12 - magnetic yoke proper 11 - intermediate portion 11a - magnetic pole S]. The magnetic flux of the permanent magnet 14 also serves to attract the armature 16, and when the armature is in contact with the core 13, the former is held in its operating position by the magnetic flux of the permanent magnet 14. In order to return the armature 16, a release current is applied to the coil 40 to yield magnetic flux which cancels the magnetic flux produced by the permanet magnet 14 in the armature 16.

Figure 7 illustrates another embodiment of the self-sustaining solenoid of the present invention, in which the parts corresponding to those in Figure 3 are identified by the same reference numerals. In this embodiment, a disc-shaped flange 50 formed from magnetic material is mounted by means of pressing, staking or monoblock casting on that portion of the armature 16 projecting out of the magnetic yoke 42. The spacing between the magnetic yoke 42 and the flange 50 in the inoperative state of the armature 16 is selected to be substantially the same as the gap 18 so that the flange 50 may contact over the entire area of its surface with the magnetic yoke 42 when the armature 16 makes confact with the core 13. Accordingly, when the armature 16 is in contact with the core 13, the aforementioned second closed magnetic path runs through the flange 50 instead of running through the non-magnetic cylindrical member 15. In this case, the second closed magnetic path is established via a route [magnetic pole N - intermediate portion 11a - magnetic yoke proper 11 - coupling portion 12 - core 13 - armature 16 - flange 50 - magnetic yoke 42 - magnetic pole S]. Therefore, magnetic flux does not pass through the cylindrical member 15 but instead passes through the flange 50 so that the flux confined within the second closed magnetic path increases, permitting an increase in the force acting to retain the armature 16. It has been found that a solenoid without the flange 50 having a retaining force of about 1500 g was increased up to 2600 g by the provision of the flange 50.

While in the foregoing embodiments the permanent magnet 14 is described as being mounted on the outside of one end of the magnetic yoke 10, it may also be attached to the inside of the magnetic yoke 10. For instance, in the case where the permanent magnet 14 is attached to the magnetic yoke 10 on the side of the projecting end of the armature 16 as shown in Figure 3, the permanent magnet 14 is mounted on the inside of the magnetic yoke 10 in contact therewith as depicted in Figure 8 and the magnetic yoke 42 is interposed between the permanent magnet 14 and the flange of the bobbin 24. In this case, the size g_1 of a gap 51 defined between the outer peripheral surface of the magnetic yoke 42 and the magnetic yoke 10 is selected so as to be larger than the size g_2 of the gap 44 between the inner peripheral surface of the opening 41 of the magnetic yoke 10 and the armature 16 so that the magentic flux passing through the gap 52 may be negligibly small. When the magnetic flux produced by the operating current applied to a coil 40a passes through the gap 44 in a direction opposite to the magnetic flux of the permanent magnet 14, the magnetic flux of the permanent magnet 14 sets up a magnetic path via a route [magnetic pole N - magnetic yoke 42 - armature 16 - core 13 - coupling portion 12 - magnetic yoke proper 11 - intermediate portion 11a - magnetic pole S] without passing through the gap 44, thus attracting the armature 16 to the core 13. When applying the release current to a coil 40b, there is produced magnetic flux which is opposite in direction to the magnetic flux of the permanent magnet 14 directed from the armature 16 to the core 13, thereby freeing the armature 16 from the core 13. The magnetic flux emanating from the coil 40b and the magnetic flux of the permanent magnet 14 passing through the gap 44 coincide in direction, so that the magnetic flux emanating from the permanent magnet 14 selects the magnetic path including the gap 44. In the embodiment of Figure 8, the coil 40 is made up of the operating and release coils 40a and 40b, and the provision of such two coils is also applicable to the other embodiments of the resent invention described herein. In other words, in the self-sustaining solenoid of the present invention, the operating and the release current may be supplied to individual coils or the same coil. Similarly, also in the embodiment of Figure 6 in which the permanent magnet 14 is mounted on the magnetic yoke 10 on the side of the core 13, the permanent magnet 14 can be mounted inside the magnetic yoke 10 as shown in Figure 9, in which the parts corresponding those in Figures 6 and 8 are identified by the same reference numerals though no description will be repeated.

Although in the foregoing only one permanent magnet 14 is disposed on one end of the magnetic yoke 10, it is also possible that a plurality of permanent magnets are sequentially arranged with a magnetic yoke interposed between adjacent ones of them in the direction of movement of the armature 16 in such a manner that adjacent ones of the permanent magnets may be of the same polarity so as to increase the attractive force for actuating the aramture 16 and to increase the force for holding the armature 16 in contact with the core 13. Figure 10 shows an example of such an arrangement. This is a combination of the arrangements of Figures 3 and 6, and the armature 16 projects through an opening 52 in the coupling portion 12 of the magnetic yoke 10. On the outside and inside of the coupling portion 12 are mounted permanet magnets 14_1 and 14_2, and mgnetic yokes 42_1 and 42_2, respectively. The permanent magnets 14_1 and 14_2 have their magnetic poles of the same polarity opposing each other across the coupling portion 12 of the magnetic yoke 10. The gap 44 is defined between the inner peripheral surface of the opening 52 of the coupling portion 12 and the outer peripheral surface of the armature 16, and its size g_2 is smaller than that g_3 of the gap 18.

When the armature 16 is out of contact with the core 13, magnetic fluxes ϕ_1 and ϕ_1' emanating from the respective permanent magnets 14_1 and 14_2 are each confined in a closed magnetic path in which they pass through the gap 44 in the same direction as shown. These magnetic fluxes do not pass

through the gap 18 and, consequently, the armature 16 is not attracted by the permanet magnets 14_1 and 14_2. The permanent magnets 14_1 and 14_2 would rather serve to retain the moving armature 16 at its outermost position against an external force when applied thereto by chance. When an operating current is supplied to the coil 40 a magnetic flux ϕ_3 is produced which passes through the gap 44 in a direction opposite to the magnetic fluxes ϕ_1 and ϕ_1', and as illustrated in Figure 11 the magnetic fluxes ϕ_1 and ϕ_1' divert to pass through the gap 18 instead of the gap 44. As a result, the armature 16 is exposed to the magnetic fluxes ϕ_1 and ϕ_1' as well as ϕ_3; so that, the attraction force is larger than is obtainable in the embodimen of Figure 3.

Even if the operating current is cut off when the armature 16 is in contact with the core 13, the magnetic fluxes ϕ_1 and ϕ_1' pass through the armature 16 and the core 13 instead of passing through the gap 44 as shown in Figure 12, thus maintaining the armature 16 in its operative position. Since this retaining force is derived from both the magnetic fluxes ϕ_1 and ϕ_1', it is larger than in the case where one permanent magnet is used. When in order to return the armature 16 to its initial or inoperative position, a release current is applied to the coil 40, a magnetic flux ϕ_3' is generated which is reverse in direction to the magnetic fluxes ϕ_1 and ϕ_1' as shown by the broken line in Figure 12.

In the case where a plurality of permanent magnets is provided, it is possible to adopt an arrangement in which the magnetic fluxes of the respective permanent magnets pass through individual gaps when the armature 16 lies in its outermost or inoperative position. For instance, as depicted in Figure 13 in which the parts corresponding to those in Figure 10 are identified by the same reference numerals, the magnetic yokes on the outside of the permanent magnets 14_1 and 14_2 are coupled as coupling portions 12_1 and 12_2 with both end portions of the magnetic yoke proper 11, and gaps 44_1 and 44_2 are defined between the inner peripheral surfaces of the openings 52_1 and 52_2 of the coupling portions 12_1 and 12_2 and the outer peripheral surface of the armature 16, and then the magnetic yoke 42 is interposed between the permanent magnets 14_1 and 14_2.

More permanent magnets may also be provided as illustrated in Figures 14 and 15 which correspond to Figures 10 and 13, respectively. In Figures 14 and 15, four permanent magnets 14_1 to 14_4 are employed. In Figures 14 and 15, those of the magnetic yokes disposed on both sides of the permanent magnet 14_i ($i = 1,2,\ldots\ldots$) which are coupled with the magnetic yoke proper 11 are identified by 12_i ($i = 1,2,\ldots\ldots$) and those which are magnetically coupled with the armature 16 are identified by 42_i ($i = 1,2,\ldots\ldots$). The magnetic yokes 12_i and 42_i are arranged alternately and the gaps 44_i are defined between the magnetic yoke 12_i and the armature 16. The adjacent ones of the permanent magnets 14_1 to 14_4 have their like magnetic poles of the same polarity opposing each other across the magnetic yoke.

Also in the case where the permanent magnet 14 is provided on the magnetic yoke 10 on the side of the core 13 as shown in Figures 6 and 9, a plurality of permanent magnets can be employed as illustrated in Figures 16 and 17 in which the parts corresponding to those in Figures 6, 9, 14 and 15 are identified by the same reference numerals though not described in detail. Further, although in the foregoing a permanent magnet is disposed only on one end of the magnetic yoke 10 in the direction of travel of the armature 16, permanent magnets may also be disposed at both ends of the magnetic yoke 10. Such an example is depicted in Figure 18, in which the parts corresponding to those in Figures 3 and 6 are identified by the same reference numerals, and no detailed description will be given. In Figure 18, the spacer 43 between the permanent magnet 14_1 and the cylindrical member 15 is formed as a unitary structure with the bobbin 24, and a pin 54 for engagement with a load is fixedly inserted into the load engaging hole 16a of the armature 16. Such modifications are applicable to the above-described embodiments as well.

In the foregoing embodiments, the permanent magnet(s) 14 have been described as having their magnetization direction parallel to the direction of movement of the armature 16. It is also possible to use a permanent magnet of annular form magnetized in a radial direction as illustrted in Figure 19. One of the magnetic poles of the permanent magnet 14 is magnetically coupled with the armature 16 and the other pole is coupled with the intermediate portion 11a via a ring-shaped coupling yoke 55. Particularly, when adopting such a permanent magnet 14 shown in Figure 19 into the embodiment of Figure 8, for example, the permanent magnet 14 can be inserted between the yoke proper 11 and the armature 16 to magnetically couple therewith in a close relation, and the space originally occupied by the magnet 14 in Figure 8 can be left empty or filled with a nonOmagnetic material.

Moreover, in any of the foregoing embodiments, a plurality of permanent magnets may also be disposed at equal intervals around the armature 16 or the core 13 in place of the single-shaped permanent magnet. Moreover, the magnetic yoke proper 11 may also be tubular in shape.

In the case where a plurality of permanent magnets are arranged in the direction of movement of the armature 16, the number of permanent magnets used may be odd as will easily be seen from the fact that even if the outermost permanent magnet 14_1 and magnetic yoke 42_1 were removed, for instance, in Figure 14 the operation of the self-sustaining solenoid would be carried out.

CLAIMS

1. A self-sustaining solenoid which is provided with operating and release coil means supplied, in use, with an operating or a release current; an armature disposed in the operating and release coil means substantially coaxially therewith in a manner to be movable along the axis thereof, one end of the armature projecting out from one end of the coil means; a magnetizable core disposed in the operating and release coil means at one side thereof, and

magnetic yoke means provided on the outside of the operating and release coil means to extend between the core and the peripheral surface of that portion of the armature for magnetic connection therebetween, permanent magnet means disposed near at least one magnetic connecting portion disposed between the magnetic yoke means and the armature or between the magnetic yoke means and the core in such a manner that one of the magnetic poles of the permanent magnet means is magnetically connected to the magnetic yoke means and the other pole of the permanent magnet means is magnetically connected to the armature and/or the core on which side the permanent magnet means is disposed, the magnetic fluxes emanating from the permanent magnet means being mostly confined within a closed magnetic path running through the armature, the core and the magnetic yoke means when the armature is in contact with the core; and a magnetic gap means provided in at least one of the magnetic connecting portions between the ends of the magnetic yoke means and the armature and the core on which side the permanent magnet means is disposed, the magnetic gap means having a size smaller than the distance between the armature and the core when the armature is in its released position spaced from the core and being so designed as to permit the passae therethrough of most of the magnetic fluxes of the permanent magnet means when the armature is held at its released position.

2. A self-sustaining solenoid according to Claim 1, wherein one end face of the magnetic yoke means in the direction of movement of the armature is formed as an end plate having an opening made therein; either the armature or the core being disposed in the opening; and the magnetic gap means is defined between the outer peripheral surface of either the armature core or the core and the inner peripheral surface of the opening.

3. A self-sustaining solenoid according to Claim 1, wherein one end face of the magnetic yoke is formed as an end plate and the armature projects through the opening, one of the magnetic poles of the permanent magnet means contacting the outside or inside surfaces of the end plate; a plate-shaped magnetic yoke having a hole receiving the armature contacted by the other magnetic pole of the permanent magnet means; and the magnetic gap means being defined between the inner peripheral surface of the opening of the end plate and the outer peripheral surface of the armature.

4. A self-sustaining solenoid according to Claim 1, in which one end of the magnetic yoke means is formed as an end plate having an opening and the core is inserted into the opening; one of the magnetic poles of the permanent magnet means is in contact with one of the inside or outside surfaces of the end plate; a plate-shaped magnetic yoke magnetically tightly coupled with the core is in contact with the other magnetic pole of the permanent magnet means, and the magnetic gap is defined between the outer peripheral surface of the core and the inner peripheral surface of the opening.

5. A self-sustaining solenoid according to Claim 1, wherein the permanent magnet means comprises a plurality of permanent magnets arranged in the direction of movement of armature with the like poles of adjacent permanent magnets facing each other; a plurality of plate-shaped magnetic yokes are provided between adjacent ones of the permanent magnets and at opposite ends of the permanent magnets, and in contact therewith in such manner that alternate ones of the plate-shaped magnetic yokes contact with the magnetic yoke means to achieve the magnetic connection between the permanent magnet means and the magnetic yokes are magnetically coupled with one of armatures or cores to achieve the magnetic connection between the permanent magnet means and said one of the armature or core; and there are provided a plurality of gaps each between said alternate ones of the plate-shaped magnetic yokes and said one of the armature and the core to form said magnetic gap means.

6. A self-sustaining solenoid according to Claim 1 wherein the permanent magnet means comprises first and second permanent magnets respectively disposed on the magnetic yoke at both sides thereof in the direction of movement of the armature; the first and second permanent magnets are magnetized in the direction of movement of the armature; magnetic fluxes emanating from the first and second permanent magnets mostly passing through the armature, the core and the magnetic yoke means when the armature is in contact with the core; the magnetic gap means comprises first and second magnetic gaps formed between both ends of the magnetic yoke means and the armature and the core, the first and second magnetic gaps being smaller than the distance between the armature and the core when the former is held in its released position spaced apart from the latter and through which the magnetic fluxes of the first and second permanent magnets mostly pass; and the magnetic flux resulting from the application of an operating current to the operating and release coil means passing through the first and second magnetic gaps.

7. A self-sustaining solenoid according to any one of Claims 1 to 6, wherein the permanent magnet means is ring-shaped and is magnetized in its axial direction.

8. A self-sustaining solenoid according to any one of Claims 1 to 3, wherein the permanent magnet means is ring-shaped and is magnetized in its radial direction.

9. A self-sustaining solenoid according to any one of Claims 1 to 6, wherein a non-magnetic spacer is interposed between the permanent magnet means and whichever of the armature and the core is disposed opposite thereto.

10. A self-sustaining solenoid according to any one of Claims 1 to 6, wherein the operating and release coil means is composed of an operating coil supplied in use, with an operating current and a release coil disposed coaxially with the operating coil and supplied in use, with a release current.

11. A self-sustaining solenoid according to Claim 3, wherein the permanent magnet means is disposed on the outside of the end plate; and a spacer formed as a unitary structure with a bobbin for the

oerating and release coil means extends between the permanent magnet means and the armature across the magnetic gap means.

12. A self-sustaining solenoid compirising the combinations and arrangements of parts substantially as hereinbefore described with reference to Figures 3-19 of the accompanying drawings.

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